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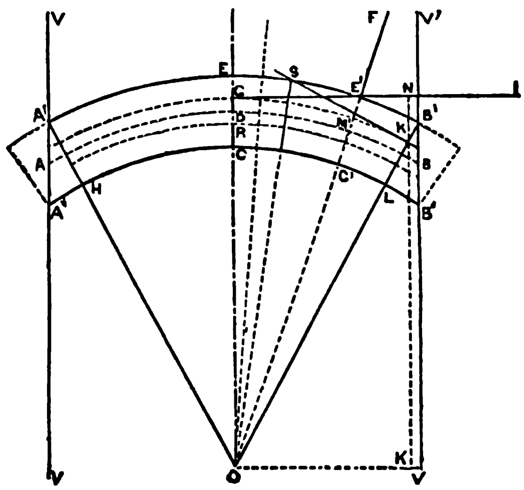
and at a sufficient distance from the outer edge B to prevent the pressure in this point from exceeding the limit R′.

In the case, on the contrary, in which the wall, being of the arched form, transmits the thrust F laterally, this force is destroyed by the reaction of the earth, and thus does not combine with the weight P.

It seems from this that, in certain cases, the thickness at the base may be reduced; but to treat the question thoroughly, we must find the thickness to be given to a barrage, so that the masonry which transmits the thrust laterally shall not bear in any point a pressure greater than the limit R′.

Suppose A′ E B′, A″ C B″, Fig. 2274, to represent a horizontal section at a distance H below the top, and the lines V V, V′ V′, the section of the sides of the valley through the same horizontal plane. The thrust F of the water in each point E′ of the inner face A′ E B′ of the wall is normal to this curve. The determination of the thickness C E to be given to the wall offers a close analogy to the ordinary problem concerning the stability of arches; only the pressures upon each voussoir, instead of being parallel with each other and equal to the weight of this voussoir, are all normal to the outer curve A′ E B′, and equal to each other, if we suppose the arch divided into equal voussoirs.

2274.



These conditions render the problem easier of solution than for the case of an ordinary arch, and enable us to find an equation which gives at once the depth at the crown.

Admitting that the curve A′ E B′ is an arc of a circle having its centre at O, suppose the thickness C E at the crown determined by the condition that the curve of the pressures passing by the point G, the pressure at the nearest extremity E shall be equal to the limit R′. The curve of the pressures is necessarily perpendicular to all the actions of the pressure of the water upon the arch which converge to the centre O, and, consequently, this curve is a circle concentric to that which forms the outer face.

This granted, to ensure the stability of the structure, there must be equilibrium in the half-arch E C L B′ between the reaction of the abutment at the point K, the pressures of the water between the points E and B′, and the reaction R of the half-arch A′ H E C.

This condition of stability leads to the following equation;

$$\Sigma M_k F = R \times KN, \qquad [44]$$

which expresses the sum of the moments of the thrust of the water with respect to the point K as equal to the moment of the reaction R with respect to the same point.

Let $OE = \rho$, $OG = \rho'$; and let the angle E O B′ be represented by A, the variable angle formed by the direction of any joint C′ E′ with the radius O B′ by a, and the pressure of the water to the unit of surface at the depth considered by Ω.

The pressure of the water upon an element E′ of the facing A′ E B′ is represented by $\Omega\, ds$, or by $\Omega \rho\, d a$, since we have $ds = \rho\, d a$.

The moment with respect to the point K of the elementary pressure F is thus

$$\Omega \rho\, d a\, MK = \Omega \rho \rho' \sin. a\, d a,$$

and, consequently, $\Sigma M_k F = \int_{a=O}^{a=A} \Omega \rho \rho' \sin. a\, d a = \Omega \rho \rho' (1 - \cos. A)$.

Again, $KN = \rho' (1 - \cos. A)$, and, consequently, equation [44] becomes

$$\Omega \rho \rho' (1 - \cos. A) = R \rho' (1 - \cos. A),$$

or $\Omega \rho = R$. And as $\Omega = \frac{H^2 \delta}{2}$,

$$R = \frac{H^2 \rho \delta}{2}. \qquad [45]$$

The value of R being determined, the thickness $EC = x$ may be immediately deduced.

The pressure to the unit of surface upon the joint E C in the point E, where it is greatest, must be equal to the limit R′. This condition is easily expressed by means of formula [10];

$$\frac{2}{3} \frac{P}{u \delta'} = \lambda.$$

It is sufficient to make $u = \frac{x}{3}$. $P = R$, and we obtain $\frac{2R}{x} = \lambda \delta'$, or substituting the value [45] of R;

$$x = \frac{H^2 \rho \theta}{\lambda}. \qquad [46]$$

We must remark that a stone structure is capable of resisting as an arch only so long as the thickness at the crown is not too great with respect to the radius. The present state of science, in the matter of the stability of arches, does not enable us to lay down with mathematical precision the limiting value of this relation, but we may consider as certain that the hypotheses which led us to formula [46] will not be realized if the thickness at the crown exceeds the third of the radius. Let us, therefore, take as the limit of x, $x = \frac{\rho}{3}$, and calculate the corresponding value of H.

Formula [46] becomes $\frac{\rho}{3} = \frac{H^2 \rho \theta}{\lambda}$, and we deduce from it

$$H = \sqrt{\frac{\lambda}{3\theta}}. \qquad [47]$$

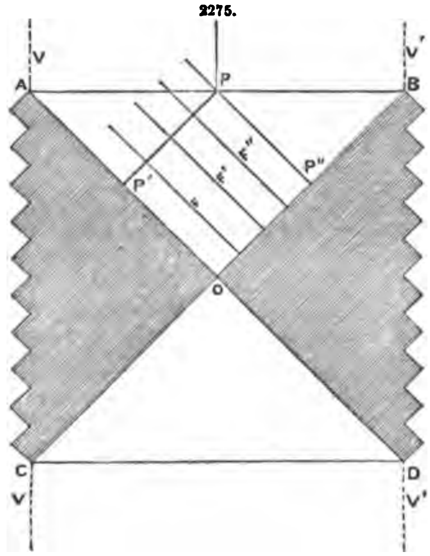
Making $\lambda = 30$, and $\theta = \frac{1}{2}$, we obtain $H = 4 \cdot 47$, whence we must conclude that for barrages of a height greater than $4^{m} \cdot 47$ we should be obliged to adopt a thickness at the crown much too great with respect to the dimensions of the radius to allow the materials to resist as an arch.

Maximum Breadth of the Profile at the Base in Narrow Valleys.—In the case of narrow valleys, the retaining wall of a barrage is built into the rocks on each side, and this circumstance allows us to adopt a thickness somewhat less than that required when the wall resists by its own weight only.

It is evident that the walls of a reservoir need never possess a thickness greater than the breadth of the valley at the height considered.

Let V V′ V V′, Fig. 2275, be the section of the sides of the valley. A B C D is the horizontal section of a wall having a thickness D B equal to the breadth A B of the valley at the height considered; trace the diagonals A D, C B, of the square A B C D. A barrage composed of the triangles A O B, C O D, would be sufficient to resist the pressure of the water; indeed, the thrust being at each point directed perpendicularly to the surface pressed, we see that all the forces, such as F, F′, F″, pressing against the face A B will meet the rock between the point D and the point B, and that their action will be destroyed by the resistance of this rock. It will be the same with respect to the forces applied to A O.

2275.



Practically, we must suppose the triangle A O B filled with masonry to support the upper portion of the barrage, which, corresponding to a greater breadth in the valley, has been constructed to resist by its weight the action of the water. But the barrage formed by the square A B C D will evidently resist as well as that formed by the two triangles A O C, B O D; the part A O B will act like a wedge designed to transmit the pressure exerted upon the face A B perpendicularly to the diagonals A O and O B. The resultant P of the actions of the thrust upon the face A B is resolved into two forces P′ and P″ normal to the diagonals O B, A O, which produce upon these faces the same action as that exerted by the direct thrust of the water in the case in which the triangle A O B is supposed removed.

We see from the foregoing considerations that a wall having the thickness of the valley to be barred will transmit directly to the sides of the valley the horizontal actions of the thrust of the water, and that it will thus run no risk of being overthrown. But to ensure the stability of the structure in a satisfactory manner from the point of view of the resistance of the materials, the thrust of the water must in no point give rise to a pressure greater than R′.

The height which a barrage may have without exceeding the limits of this condition is easily determined. The pressure exerted to the unit of surface on the face A B is represented by $H \delta$; this pressure gives rise to two forces perpendicular to the diagonals C B A B or to the surface of the rocks arranged in gradations parallel to these diagonals the value of which is $\frac{H \delta}{\sqrt{2}}$. To ensure this stability, this pressure must be equal at the most to $R' = \lambda \delta'$, and, consequently, we ought to have $\frac{H \delta}{\sqrt{2}} = \lambda \delta'$; whence $H = \frac{\lambda}{\theta} \sqrt{2}$. Admitting as before, $\lambda = 30$, $\theta = \frac{1}{2}$, we obtain $H = 84 \cdot 852$. Hence we conclude that so long as the height of the barrage does not exceed

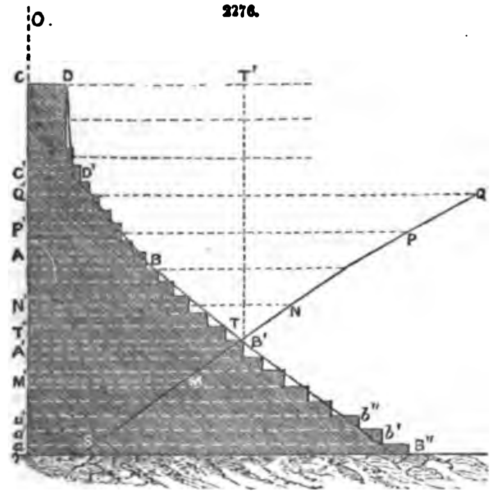
$84^m \cdot 852$, it is not necessary to give it a thickness greater than the breadth of the valley to enable it to resist the action of the water. As barrages never reach this height, we may conclude in a general manner that the wall of a reservoir will always be capable of resisting the action of the water, if at all points it possesses a thickness equal to the breadth of the valley.

To determine a Profile for a Valley of given Dimensions.—If it be wished to apply to a valley of a determinate breadth, a profile calculated according to the conditions laid down in the early portion of these remarks, its thickness may be reduced when it reaches a value equal to the breadth of the valley. The height beyond which the thickness cannot be calculated according to those conditions may be determined by a very simple geometrical construction. Thus, Fig. 2276, draw perpendicularly to the right line O O' the breadths O B'', A'B', A B, C' D', C D, of the barrage considered at the various heights, and draw also the breadths O S, M' N, N' N, P' P, Q' Q, of the valley. Join the points B'', B', B', D', D, which are the extremities of the first perpendiculars; join in like manner the extremities of the S, M, N, P, etc., of the second series of perpendiculars. The distance T T' from the point T, where these two lines meet at the top of the barrage, will be the height sought.

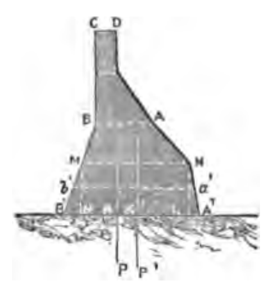
By giving to the barrage from the height T T' a thickness T T' equal to the breadth of the valley at this point, we shall ensure its being capable of resisting the action of the water. At the lower part there will be an excess of section, since the breadth of the valley decreases, and since it is sufficient for the wall to have in every point a thickness equal to this breadth.

But it will also be necessary to see that the vertical forces which continue to be transmitted to the foundations do not, in any point, produce a pressure to the unit of surface greater than the limit R'. This consideration will require an increase in the thickness of the wall from the point T, but it will be less considerable than in the case in which the wall resists by its own weight, because the thrust F, being destroyed by the lateral resistance of the abutments, will not have the effect of driving the point of application E of the vertical force upon the base towards the outer edge A', as in the case of Fig. 2272, for example.

2276.



2277.



The dimensions of the lower portion of the profile may be calculated by the following considerations;—Let M N, Fig. 2277, be the horizontal plane passing through the height just determined; let $M N = b$, $M H = h'$, $s \delta'$ the weight of the upper portion C D M N of the barrage, $s' \delta$ the weight of the water acting upon the inclined surface M B, α the distance at the point M from the centre of gravity of the portion C D M N, and β the distance at the point N from the vertical resultant of the actions of the weight of the masonry and of the water upon the face M B. We will take as unknown $B' H = y$ and $L A' = x$.

The question may be solved in the same way as those which we have already treated, namely, by expressing the pressure to the unit of surface at the points A' and B', according as the reservoir is full or empty, as equal to the limit R'. The equations of the problem will still be the expressions [9] and [10], $2\left(2 - \frac{3u}{l}\right)\frac{P}{\delta' l} = \lambda$, $\frac{2}{3}\,\frac{P}{u\,\delta'} = \lambda$, in which we must substitute for the quantities P, l, u, their values as functions of the data of the question.

Considering, in the first place, the case in which the reservoir is full, we have

$$P = s\delta' + s'\delta + b h' \delta' + \frac{h' x}{2} + \frac{h' y}{2} + \left(\frac{2h + h'}{2}\right) y \delta.$$

Making, for greater convenience,

$$s + s'\theta + b h' = \sigma, \text{ and } 2h + h' = H', \; P = \frac{\delta}{2}\,[2\sigma' + h' x + y\,(h' + H'\theta)].$$

Again, $u = A K = x + L K$.

The value of L K is found by expressing the moment of the whole weight P, with respect to the point N, as equal to the sum of the moments of the vertical forces composing it.

Making $(s + s'\theta)\,\beta + \dfrac{b^2 h'}{2} = \mu''$, we thus obtain

$$u = \frac{(2h' + 3h'\theta)\,y^2 + 6\,(h' + H'\theta)\,x\,y + 4\,h'x^2 + 6\,b\,(h' + H'\theta)\,y + 12\,\sigma' x + 12\,\mu''}{6\,(2\,\sigma' + h'x + y\,(h' + H'\theta)}$$

Substituting this value of u as well as those of P and $l = b + x + y$ in [9] and [10], we obtain the following equations;—

$$\left.\begin{array}{l|l|l|l|l|l} 2\lambda & y^2 + 4\lambda & x\,y + 2\lambda & x^2 + 4\,b\,\lambda & y + 4\,b\,\lambda & x + 2\,\lambda\,b^2 \\ - H'\theta & + 2\,H'\theta & & + 2\,b\,H'\theta & - 4\,b\,h' & + 12\,\mu'' \\ - 2\,h' & - 2\,h' & & + 2\,b\,h' & + 4\,\sigma' & - 8\,\sigma' b \\ & & & - 8\,\sigma' & & \end{array}\right\} = 0. \quad [48]$$

$$\left.\begin{array}{l|l|l|l|l|l} 2\,h'\lambda & y^2 + 6\,h'\lambda & x\,y + 4\,h'\lambda & x^2 + 6\,b\,h'\lambda & y + 12\,\lambda\,\sigma' & x + 12\,\mu''\lambda \\ + 3\,H'\theta\lambda & + 6\,H'\theta\lambda & - 2\,h'^2 & + 6\,b\,H'\lambda\theta & - 8\,h'\sigma' & - 8\,\sigma' \\ - 4\,H'h'\theta & - 4\,H'h'\theta & & - 8\,\sigma' h' & & \\ - 2\,H'^2\theta^2 & - 4\,h'^2 & & - 8\,H'\theta\sigma' & & \\ - 2\,h'^2 & & & & & \end{array}\right\} = 0. \quad [49]$$

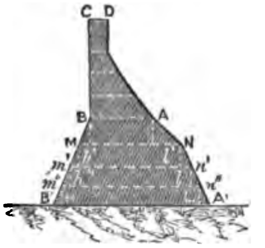
The first or the second of these equations will be required according as u is greater or less than

$$\frac{b + x + y}{3}.$$

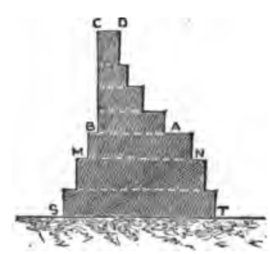
The pressure to the unit of surface at the point B′ when the reservoir is empty, which pressure is equal to the limit R′, remains to be expressed. The equations expressing this condition differ in nothing from those numbered [30] and [31]. Combining one of these two equations with one of the equations [48] and [49], we may determine the unknown x and y.

Having determined by the preceding conditions the lower portion M N B′ A′ of the profile, we shall be sure that the pressure to the unit of surface in A′ or B′, according as the reservoir is full or empty, will be equal to the limit R′, and that at the same time the pressure at the corresponding points a' and b' of the same horizontal section will be less than this limit. The cube of the masonry may be determined by dividing the surface M N B′ A′ into a certain number of zones, such as M N, $m' n'$, $m'' n''$, and so on, and calculating the lengths $m' h'$, $l' n'$, $m'' h''$, $l'' n''$, and so on, Fig. 2278, to the condition that the pressures at the points $m' n'$, $m'' n''$, shall be equal to the limit adopted. The preceding formulæ will serve to solve this question; it will be sufficient to suppose that H′, instead of offering the height M H, is equal to the height M h' of the sections.

2278.



2279.



If a graduated facing be employed in the upper portion, it will be well to employ the same system in the lower portion, Fig. 2279.

The calculations are made in exactly the same way as those which we have developed, always denoting the edge of the outer gradations by x, and that of the inner gradations by y. The equations [48], [49], [30], and [31], are replaced by the following;—

$$\left.\begin{array}{l|l|l|l|l|l} \lambda & y^2 + 2\lambda & x\,y + \lambda & x^2 + 2\,b\,\lambda & y + 2\,b\,\lambda & x + \lambda\,b^2 \\ - h' & - 2\,h' & - h' & + 2\,b\,h' & + 2\,\sigma' & + 6\,\mu'' \\ - h\,\theta & + 2\,h\,\theta & & + 2\,b\,h\,\theta & - 4\,b\,h' & - 4\,b\,\sigma' \\ & & & - 4\,\sigma' & & \end{array}\right\} = 0. \quad [50]$$

$$\left.\begin{array}{l|l|l|l|l|l} 3\,h'\lambda & y^2 + 6\,h'\lambda & x\,y + 3\,\lambda\,h' & x^2 + 6\,b\,h'\lambda & y + 6\,\lambda\,\sigma' & x + 6\,\lambda\,\mu'' \\ + 3\,h\,\theta\,\lambda & + 6\,h\,\theta\,\lambda & - 4\,h'^2 & + 6\,b\,h\,\theta\,\lambda & - 8\,h'\sigma & - 4\,\sigma'^2 \\ - 4\,h^2\theta^2 & + 8\,h\,h'\theta & & - 8\,\sigma' h\,\theta & & \\ - 8\,h\,h'\theta & - 8\,h'^2 & & - 8\,\sigma' h' & & \\ - 4\,h'^2 & & & & & \end{array}\right\} = 0. \quad [51]$$

$$\left.\begin{array}{l|l|l|l|l|l} \lambda & y^2 + 2\lambda & x\,y + \lambda & x^2 + 2\,\sigma & y + 2\,b\,\lambda & x + \lambda\,b^2 \\ - h' & - 2\,h' & - h' & + 2\,b\,\lambda & - 4\,\sigma & + 6\,\mu' \\ & & & - 4\,b\,h' & + 2\,b\,h' & - 4\,b\,\sigma \end{array}\right\} = 0. \quad [41]$$

$$\left.\begin{array}{l|l|l|l|l|l} 3\,h'\lambda & y^2 + 6\,\lambda\,h' & x\,y + 3\,h'\lambda & x^2 + 6\,\lambda\,\sigma & y + 6\,b\,h'\lambda & x + 6\,\lambda\,\mu' \\ - 4\,h'^2 & - 8\,h'^2 & - 4\,h'^2 & - 8\,h'\sigma & - 8\,h'\sigma & - 4\,\sigma^2 \end{array}\right\} = 0. \quad [42]$$

Application of the Theory to the Calculation of Various Profiles of Dams.—To render more complete the theoretical considerations which we have developed above, we have applied them to the determination of the profile of a barrage 50 mètres in height and unlimited in length, and of that of the barrage of the Furens which dams the valley at a point where it is only 7 mètres broad at the bottom.

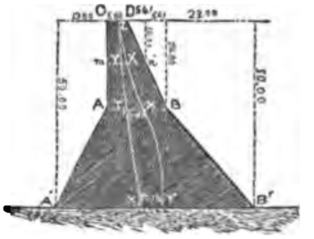
In these calculations we have supposed that the density of water being equal 1000, that of the

masonry would be equal to 2000, so that we have $\delta' = 2000$, $\delta = 1000$, $\theta = \frac{1}{2}$. In choosing the limit R′ for the pressure to the unit of surface on the masonry and on the soil of the foundations, we were led to adopt 6 kilogrammes to the square centimètre, or 60,000 kilogrammes to the square mètre, so that in these calculations we have $R' = 60,000$ and $\lambda = 30$. By admitting this limit, we shall keep within the conditions of stability. The walls of the barrage of Bosmeleac, to which we have before alluded, and of Clomel on the canal from Nantes to Brest, support, in certain points a pressure greater than 6 kilogrammes to the square centimètre, and these structures are in a state of perfect preservation.

Profiles with Inclined Facings applied to Walls of 50 *mètres in height.*—In the first place, we determined two profiles for valleys of great breadth by means of the calculations developed in the early portion of these considerations. These profiles are represented by Figs. 2240 and 2280. To the former of these we have already called attention when speaking of the barrage of the Furens.

By means of the equations [16] and [18] we first determined the height C A, Fig. 2280, throughout which the inner face might be vertical, and the corresponding breadth A B. We then admitted that the lower portion of the barrage should terminate in two inclined facings A A′, B B′, and the dimensions of this portion of the structure were determined by means of the equations [28] and [30]. The barrage thus constructed possesses this property, namely, the pressure to the unit of surface in the points A, B, A′, B′, is equal to 6 kilogrammes to the square centimètre, but less than this limit for any horizontal section, such as $m\,n$, other than A B, and A′ B′. Thus the pressure at the point n in the horizontal plane passing through the middle of C A, is equal to only $1^{k}\cdot 79$ to the square centimètre.

2280.



The profile of Fig. 2240 is constructed in accordance with more economical conditions. We have supposed each of the portions C D B A, A B A′ B′, into which the profile is necessarily subdivided, itself divided into two portions. The dimensions of the portion C D $m\,n$ were determined by means of equation [22], in which the height h was made equal to 12·00. The breadth $m\,n$ having been calculated, the dimensions of the part $m\,n$ A B were found by means of the equations [17] and [19]. To construct the lower portion A m' A′ B′ n' B, the height of 24 mètres which it possesses was supposed divided into two equal portions, and recourse was had to the equations [29] and [31] to determine successively the breadths $m'\,n'$ and A′ B′.

A profile so determined incurs a pressure equal to the limit R′ only through the sections $m\,n$, A B, $m'\,n'$ A′ B′; for all other sections this pressure is less than 6 kilogrammes to the square centimètre, as may be seen in Table A, columns 11 and 12 containing the pressures when full and when empty upon sections taken at every 2 mètres from the top. We may remark that the pressures when full are, in the upper portion, far from reaching this limit; this will not be surprising when it is borne in mind that the theoretical profile ought to have a thickness nul at the summit, whilst we have been led to give it a breadth of 5 mètres. The curves of the pressures when full and when empty are described on Fig. 2240; Z X X X is the curve relative to the case in which the reservoir is full, and Z Y Y Y is the curve when empty. The abscissæ such as X m Y n of these curves, which are nothing but the value of u in the expressions [1] and [2] that give the pressures, are placed in columns 9 and 10 of Table A.

The profile we are considering is in good conditions of stability with respect to the pressure supported by the masonry: it remains to be proved whether the stability be equally sure with respect to the slipping of the courses of the masonry one over another, and of the whole structure upon the soil of the foundation. We have seen that to ensure the stability of the structure in regard to this question of slipping, we must have for each course $2\left(\frac{s\,\delta' f - \gamma b}{\delta\,H^2}\right) > 1$, or at the limit

$$2\left(\frac{s\,\delta' f + \gamma b}{\delta\,H^2}\right) = 1. \qquad [43]$$

In this equation f represents the coefficient of friction on the masonry, γ the force of cohesion in the masonry to the unit of surface, b the breadth of the profile in the course considered, and s the surface of the portion situate above this course.

Neglecting the cohesion of the masonry, and thus assuming unfavourable conditions, equation [43] becomes $\frac{2\,s\,\delta' f}{\delta\,H^2} = 1$, or $f = \frac{\frac{\delta\,H^2}{2}}{s\,\delta'}$.

In column 8 of Table A will be found the value of this quantity, which is none other than that of the ratio of the thrust to the vertical pressure. It will be seen that the maximum value it attains is 0·7304, and as $0^{m}\cdot 76$ is usually admitted for the coefficient f, we may conclude that the profile of Fig. 2240 is in good conditions of stability with respect to slipping, even when we do not take into account the cohesion of the mortar.

Profile of Equal Resistance calculated by the Approximative Method for a Wall 50 *mètres in height.*—The principles developed by us respecting the determining of a profile differing but little from one of equal resistance, have been applied to a barrage 50 mètres in height. The upper portion C D B A of this profile, which was represented in Fig. 2241, was determined by means of the equation [36]; the remainder of the barrage was supposed to be divided into sections of a constant height of 2 mètres. The graduations included between the plane B A and C′ C″ in that portion in which the profile is vertical on the side of the water were calculated by means of the equations [37] and [38], taking care, when choosing the one suited to each graduation, to conform to the instructions which

we have already given relative to this matter. The lower portion of the barrage was calculated by means of the equations [39], [40], [41], and [42]. But as these calculations are very intricate and tedious, when a sufficient number of graduations has been determined to give nearly the form of the curves passing through their re-entering angles, we may calculate the salient angles x and y tentatively by choosing as the first approximative values those which result from the intersection of these curves produced with the horizontal planes forming the base of the graduations, and modifying these values until the pressures resulting from them are equal to 6 kilogrammes to the square centimètre. Table B, drawn up in the same manner as the Table relating to Fig. 2240, contains all that it is interesting to know with respect to the profile of Fig. 2241. It will be seen that the maximum value to be given to the coefficient of friction, to satisfy the conditions of stability with respect to slipping, is 0·7324, a value less than the limit applicable to masonry.

Comparison of the Profiles calculated.—Profile to be adopted.—There is no need of insisting upon the advantages possessed by profiles deviating but little from one of equal resistance. It is perfectly clear that a reservoir wall calculated so as to offer on certain points pressures much less than the limit not to be exceeded, might, with a more rational arrangement, have had smaller dimensions without offering less security. The profiles of Figs. 2240, 2241, differ very little from one of equal resistance; the former admits the limit of pressure only upon the sections $m\,n$, A B, $m'\,n'$, A′ B′; the latter admits it upon all the re-entering angles of the graduations. In all the other points of the facing, in both profiles, the pressure to the unit of surface is less than the limit adopted. It remains for us to compare these two profiles. From the point of view of stability with respect to the pressures, the advantages which they offer are nearly identical. The same may be affirmed with respect to the resistance to slipping; in the former, the maximum value to be given to the coefficient of friction in the masonry is 0·7034, it is 0·7324 in the latter. Either of these profiles might be chosen indifferently if no question foreign to stability had to be taken into consideration. But there are other conditions in works of such magnitude which may not be overlooked. These are the suitability of the forms adopted to the materials to be used, the cost, and the effect produced from an artistic point of view. When the materials to be employed consist chiefly of porphyry, granite, or basalt, stones which, for the most part, do not admit of being regularly cut, it becomes especially difficult to construct the facings with horizontal joints. The profile of Fig. 2241, however, requires as an indispensable condition that the facings should be so constructed, and, having regard to the slight projection of the graduation, we should be under the necessity, in order to obtain a solid structure, to cover them with stones equal in length to this projection. On the contrary, the facings of the profile of Fig. 2240 may be easily executed with materials hard to cut, by adopting the system of irregular joints, the only practicable one with the greater part of porphyries. From the point of view of cost, the profile 2240 again offers the greatest advantages; it presents, in fact, a cube of only 995^{m}·30 to the lineal mètre, whilst that of Fig. 2241 has 1028·75 cubic mètres; the surface of the exposed facings is 119·70 square mètres for the former and 152·15 square mètres for the latter. Supposing 12 francs to be the price of the cubic mètre of the ordinary masonry and 20 francs the price of the masonry of the facings, we have as the cost by the lineal mètre of Fig. 2240 the sum of 12230·88 francs, which cost is increased to 12710·28 francs for Fig. 2241, thus offering a saving of 479·28 francs in favour of the former. This saving would really be greater, for we have supposed the cost of the masonry of the facings to be the same in both cases, whilst for Fig. 2241 it would certainly be considerably greater. From the point of view of artistic effect, it seems to us that the outer face of Fig. 2240 presents a nobler aspect than the graduations of Fig. 2241.

The foregoing considerations lead us to give the preference to the profile Fig. 2240, and that is the one we should propose if we were called upon to design the wall of a large reservoir.

Before leaving this subject, we will examine some objections made to a system similar to the one we propose by M. de Sazilly. According to this well-known engineer, the principal objections to facings presenting a polygonal outline are the following;—

1. The acute angles formed by the horizontal sections of the wall and of the facings place the latter in unfavourable conditions for resisting the weight which they have to support.

2. The too gentle slope of the outer face favours the growth of parasitic plants, whose effect is always destructive.

3. The execution of a facing having a polygonal contour, while presenting an ungraceful appearance, is attended with practical difficulties.

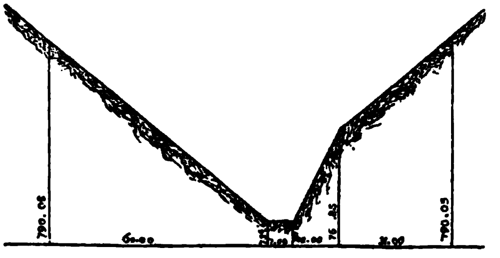
The last of these objections does not apply to Fig. 2240, since the outer face presents only four changes of inclination, the first of which is alone perceptible to the eye. The second objection applies with greater force to the horizontal portion of the graduation of Fig. 2241. True M. de Sazilly proposes to cover them with a layer of bitumen; but the growth of vegetation may be easily prevented on the facings of Fig. 2240, and with less expense, by carefully executing the joints and keeping them in a good condition. The first objection, which is certainly the most serious, is of less importance in the case of our profile than in the case of the one to which it was applied. Indeed, this latter has a polygonal contour concave with respect to the straight facings n B, B n', n' B′, of Fig. 2240, and, consequently, the sides of this polygon make with the horizontals in each point angles smaller than those of our profile. But in any case, this objection may be removed by arranging the masonry of the facings normally to the surface of these facings. With this arrangement they will certainly be in better conditions of resistance than those of the graduations of Fig. 2241, which the pressure may tend to separate from the mass of the structure along the lines which join the re-entering angles.

Profile of the Barrage 50 mètres in height constructed on the Furens.—At the part where this barrage is constructed, the valley is only 7 mètres broad at the bottom, as shown in Fig. 2281. This circumstance, as we have already seen, enables us to diminish the breadth of the barrage at the bottom. To determine the point from which, the profile having reached the breadth of the valley, the horizontal thrust is destroyed by the resistance of the rocks, we have applied succes-

sively to the profiles 2240, 2282, and 2241 the construction shown in Fig. 2276. The lines O S, M′M, N′N, P′P, Q′Q, drawn perpendicularly to the vertical line O O′, are equal to the breadth of the valley at the heights O M′, O N′, O P′, and so on, above the bottom.

The lines O B″, A′B, A B, C′D, C D, are equal to the breadth of the profile, Fig. 2240; at the heights O K, O A, O B, O C′, O C, the lines $a'b'$, $b''a''$, and so on, represent the breadths of Fig. 2241. We see from the construction that the breadth of the barrages reaches the breadth of the valley at a height above the foundation comprised between 14 and 15 mètres for Fig. 2240, and between 15 and 16 mètres for Fig. 2241. To avoid fractional numbers in the height of the sections into which the profiles are divided, we have taken 14 mètres for the first of these heights, and 15 mètres for the second. The lower portion of the profiles suitable to the valley of the Furens was calculated by means of the formulæ relative to valleys of given dimensions, and in this way were obtained the two profiles, Figs. 2242, 2243, referred to when treating of that barrage. The breadth of Fig. 2242 at the base was calculated by means of the equations [48] and [30], from which the values $A'p = y$ and $B'q = x$ were deduced. The graduations of Fig. 2243 were calculated by means of the equations [50] and [41]. These two profiles are exactly similar to those of Figs. 2240, 2241, as far as the plane $m'n'$, and Tables A and B contain all that is required to calculate their resistance. Table C contains the same elements for the lower portions; only the horizontal component of the thrust being directly destroyed by the resistance of the rocks, the slipping of one course of masonry over another is rendered impossible; for this reason we have not given in this Table the elements relating to the resistance to slipping.

2281.



It will be noticed that the curves of the pressures when full Z X X X in these two profiles present a point of retrogression where they meet the plane $m'n'$; there is nothing surprising in this, as it was from this plane that the horizontal component was supposed to be completely destroyed, but in reality the point of inflexion would have no existence, because on approaching the plane $m'n'$, before being completely destroyed, the thrust would be weakened, and thus the curve of the pressures would be brought nearer the inner face, and would assume the form shown by the dotted line.

TABLE A.

Height measured from the Top.	Volume of the Masonry to the lineal mètre.	Reduced Thickness.	Ratio of the Reduced Thickness to the Height.	Total Vertical Pressures.	Horizontal Thrusts.	Ratio of the Pressure to the Thrust.	Value to be given to the Co-efficient of Friction for Equilibrium.	Abscissæ of the Curve of the Pressures when full.	Abscissæ of the Curve of the Pressures when empty.	Maximum Pressure to the square centimètre when full.	Maximum Pressure to the square centimètre when empty.
1	2	3	4	5	6	. 7	8	9	10	11	12
				tons.	tons.					kilos.	kilos.
2	10·253	5·1265	2·5632	20·506	2·00	10·2530	0·095	2·62	2·56	0·39176	0·27002
4	21·012	5·2530	1·3131	42·024	8·00	5·2530	0·190	2·59	2·65	0·91916	0·85344
6	32·278	5·3796	0·8966	64·556	18·00	3·5864	0·275	2·50	2·69	1·56894	1·34472
8	44·052	5·5065	0·6883	88·104	32·00	2·7532	0·360	2·28	2·76	2·52140	1·84464
10	56·330	5·6330	0·5633	112·660	50·00	2·2532	0·440	1·94	2·82	3·86172	2·34540
12	69·120	5·7600	0·4800	138·240	72·00	1·9200	0·520	1·54	2·89	5·98441	2·83232
14	83·608	5·9720	0·4265	167·216	98·00	1·7062	0·585	2·21	3·02	5·04719	3·65052
16	100·993	6·3120	0·3945	201·986	128·00	1·5748	0·630	2·78	3·25	4·83752	4·15936
18	121·275	6·7375	0·3743	242·550	162·00	1·4972	0·665	3·30	3·56	4·90198	4·54354
20	144·451	7·2227	0·3611	288·908	200·00	1·4446	0·690	2·78	3·92	5·09510	4·91565
22	170·530	7·7513	0·3523	341·060	242·00	1·4082	0·705	4·24	4·32	5·36106	5·26631
24	199·503	8·3126	0·3463	899·006	288·00	1·3854	0·720	4·69	4·74	5·66761	5·60799
26	231·380	8·8992	0·3422	262·760	338·00	1·3690	0·730	5·14	5·19	6·00020	5·94619
28	267·020	9·5364	0·3406	548·855	392·00	1·4001	0·7143	6·31	6·16	5·79478	5·78522
30	307·312	10·2437	0·3404	645·240	450·00	1·4339	0·697	7·43	7·21	5·81376	5·68148
32	357·247	11·0077	0·3439	761·799	512·00	1·4879	0·672	8·57	8·23	5·85488	5·73312
34	401·828	11·8184	0·3476	869·120	578·00	1·5037	0·665	9·76	9·26	5·89248	5·75856
36	456·055	12·6682	0·3519	996·655	648·00	1·5380	0·640	10·83	10·28	5·99080	5·86768
38	514·940	13·5510	0·3567	1134·590	722·00	1·5714	0·636	12·12	12·30	6·00372	6·00088
40	579·283	14·4821	0·3620	1306·073	800·00	1·6383	0·612	13·89	12·90	5·96288	5·90304
42	649·912	15·4741	0·3684	1494·374	882·00	1·6943	0·589	15·69	14·48	5·91300	5·84984
44	726·830	16·5188	0·3754	1696·500	968·00	1·7525	0·570	17·46	16·04	5·93320	5·80800
46	810·020	17·6091	0·3828	1913·415	1058·00	1·8085	0·552	19·17	17·60	5·93620	5·85312
48	899·515	18·7399	0·3904	2145·186	1152·00	1·8621	0·537	21·00	19·14	5·92640	5·98136
50	995·300	19·9060	0·3981	2391·783	1250·00	1·9134	0·522	22·76	20·67	5·99638	5·00380

Table B.

Height measured from the Top.	Volume of Masonry to the lineal mètre.	Reduced Thickness.	Ratio of the Reduced Thickness to the Height.	Total Vertical Pressures.	Horizontal Thrusts.	Ratio of the Pressure to the Thrust.	Value to be given to the Co-efficient of Friction for Equilibrium.	Abscissæ of the Curve of the Pressures when full.	Abscissæ of the Curve of the Pressures when empty.	Maximum Pressure to the square centimètre when full.	Maximum Pressure to the square centimètre when empty.
1	2	3	4	5	6	7	8	9	10	11	12
				tons.	tons.					kilos.	kilos.
9	45·00	5·0000	0·5555	90·000	40·50	2·2222	0·4500	1·15	2·50	5·21739	1·80000
11	56·60	5·1454	0·4677	113·200	60·50	1·8710	0·5344	1·25	2·58	5·99655	2·59578
13	70·44	5·4184	0·4168	140·880	84·50	1·6672	0·5990	1·56	2·75	5·99533	0·28171
15	86·78	5·7853	0·3856	173·560	112·50	1·5427	0·6481	1·92	3·00	6·01354	3·81081
17	105·86	6·2270	0·3663	211·720	144·50	1·4652	0·6821	2·35	3·32	6·01631	4·23867
19	127·88	6·7305	0·3542	255·760	180·50	1·4169	0·7057	2·84	3·70	6·00037	4·61308
21	153·02	7·2866	0·3469	306·040	220·50	1·3879	0·7204	3·40	4·12	5·99567	4·94766
23	180·44	7·8886	0·3429	362·880	264·50	1·3719	0·7288	4·03	4·59	6·00104	5·26989
25	213·32	8·5328	0·3413	426·640	312·50	1·3652	0·7324	4·74	5·09	5·99992	5·58169
27	248·84	9·2162	0·3413	497·680	364·50	1·3653	0·7324	5·53	5·63	5·99683	5·88712
29	288·44	9·9462	0·3429	579·985	420·50	1·3792	0·7251	6·47	6·42	6·00229	5·99072
31	332·52	10·7264	0·3460	674·235	480·50	1·4031	0·7126	7·57	7·39	6·01028	5·99637
33	381·42	11·5581	0·3502	780·250	544·50	1·4329	0·6978	8·81	8·47	5·99629	5·99664
35	435·36	12·4888	0·3553	898·690	612·50	1·4672	0·6815	10·13	9·65	5·99890	5·97899
37	494·62	13·3681	0·3613	1030·335	684·50	1·5052	0·6643	11·56	10·93	6·00256	5·96272
39	559·38	14·3130	0·3677	1174·100	760·50	1·5438	0·6477	13·06	12·22	5·97624	5·99464
41	629·98	15·3653	0·3747	1333·240	840·50	1·5862	0·6304	14·67	13·65	5·98226	5·99696
43	706·70	16·4348	0·3822	1507·795	924·50	1·6039	0·6131	16·38	15·16	5·97236	5·99696
45	789·84	17·5520	0·3900	1698·585	1012·50	1·6775	0·5960	18·20	16·77	5·98106	5·99716
47	879·70	18·7170	0·3982	1906·430	1104·50	1·7260	0·5793	20·11	18·48	5·97802	5·99909
49	976·60	19·9306	0·4067	2132·190	1200·50	1·7760	0·5630	22·12	20·27	5·98188	6·00268
51	1080·00	21·1941	0·4155	2377·295	1300·50	1·8279	0·5470	24·27	22·18	5·99596	6·00160

Table C.

Height measured from the Top.	Volume of the Masonry to the lineal mètre.	Reduced Thickness.	Ratio of the Reduced Thickness to the Height.	Total Vertical Pressures.	Abscissæ of the Curve of the Pressures when full.	Abscissæ of the Curve of the Pressures when empty.	Maximum Pressure to the square centimètre when full.	Maximum Pressure to the square centimètre when empty.
1	2	3	4	5	6	7	8	9
				Fig. 2242.				
26	233·61	8·9850	0·3455	467·220	5·20	5·18	5·98493	6·00617
28	266·94	9·5335	0·3404	540·500	6·21	6·14	5·87128	5·79687
30	307·00	10·2333	0·3411	627·720	7·32	7·10	5·88208	5·39772
32	351·55	10·9859	0·3433	724·420	8·45	8·04	5·86224	5·82776
34	400·59	11·7820	0·3465	830·580	9·53	9·05	5·96656	5·93560
36	454·18	12·6161	0·3504	946·490	10·65	10·03	5·99930	6·00100
38	510·99	13·4471	0·3538	1034·740	11·57	11·14	5·07080	5·96539
40	569·82	14·2455	0·3561	1171·540	12·35	12·13	5·38948	5·97094
42	630·67	15·0159	0·3575	1301·700	13·31	13·12	5·28036	5·95388
44	693·54	15·7622	0·3582	1442·280	14·09	14·01	5·53184	5·99196
46	758·43	16·4876	0·3584	1587·580	14·82	14·86	5·63808	5·98260
48	825·34	17·1945	0·3582	1737·620	15·51	15·67	5·90902	5·98752
50	894·34	17·8868	0·3577	1892·525	16·19	16·47	6·00268	6·00148
				Fig. 2243.				
39	556·16	14·2605	0·3656	1165·255	12·75	11·99	5·99075	6·00344
41	620·20	15·1268	0·3689	1307·960	13·90	13·08	5·99693	5·99972
43	686·88	15·9739	0·3714	1457·515	15·01	14·14	5·99999	5·99435
45	756·36	16·8080	0·3735	1614·005	16·12	15·18	6·00164	5·99862
47	828·84	17·6349	0·3757	1778·865	17·24	16·24	5·99794	6·00128
49	904·48	18·4587	0·3927	1952·235	18·38	17·31	6·00044	5·99788
51	983·48	19·2839	0·3781	2134·000	19·55	18·40	5·99899	6·00040

All the reasons by which we were induced to prefer Fig. 2240 to Fig. 2241 exist in favour of Fig. 2242 against Fig. 2243. The cube of the masonry is 894·34 cubic mètres to the lineal mètre, and it is 945·40 for the second. The surfaces of the facings are respectively 112·99 and 139·50 square

mètres. Admitting the prices given above, the lineal mètre of Fig. 2242 would cost 11003·26 francs, a sum that would be increased 11679·60 francs for Fig. 2243. There would thus be a saving of 676·34 francs in favour of the former, and this saving would actually be greater by reason of the difference which would necessarily exist in the prices of the masonry of the facings. We are thus led to believe that the profile represented by Fig. 2242 is the best.

Comparing the price by the lineal mètre of Fig. 2282 with that of Fig. 2283, we find that the latter exceeds the former by 1227·62 francs. We see from this that the small breadth of the

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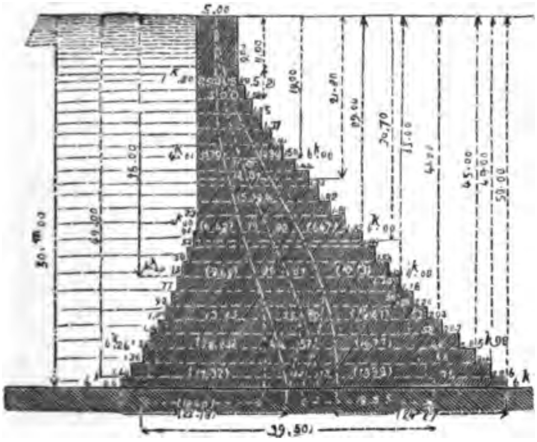
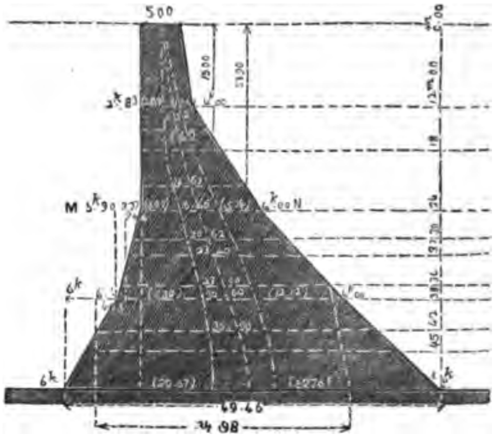


2283.



valley of the Furens enables us to reduce the cost by the lineal mètre of barrage by about one-tenth without in any degree diminishing the stability of the structure. See BARRAGE. DOCKS. DRAINAGE. EMBANKMENTS. GRAVITY. LOCKS. PRESSURE, *Centre of.* WATERWORKS. WEIRS.

DAMPER. FR., *Registre;* GER., *Rauchschieber;* ITAL., *Registro;* SPAN., *Válvula atemperadora.*

See BLAST FURNACE. BOILER, p. 390. CHIMNEY, *registers*, p. 960. FURNACES. STATIONARY ENGINES.

DASH-POT. FR., *Appareil de choc;* GER., *Stossapparat;* ITAL., *Ammorzatore a stantuffo latino;* SPAN., *Cilindro para amortiguar choques.*

See BRAKE, p. 621. CAM, p. 905.

DATUM-LINE. FR., *Plan di niveau;* GER., *Grund oder Standlinie;* ITAL., *Livello;* SPAN., *Plano de comparacion.*

A datum-line is the horizontal or base line, from which the surface points are measured or reckoned in the plan of a railway. See A. P.

DEAD-CENTRE. FR., *Point mort;* GER., *Todter Punct;* ITAL., *Punto morto.*

A dead-centre, or dead-point, is either of the two opposite points in the orbit of a crank, at which the crank and the connecting-rod lie in the same straight line. See ALGEBRAIC SIGNS, p. 42. LOCOMOTIVES. MARINE ENGINES. SLIDE-VALVES. STATIONARY ENGINES.

DERRICK. FR., *Martinet;* GER., *Dirk oder Piekfall;* ITAL., *Gru;* SPAN., *Grua.*

See LIFTS. HOISTS and ELEVATORS.

DETAILS OF ENGINES. FR., *Pièces des machines à vapeur;* GER., *Einzelne Theile einer Maschine;* ITAL., *Parti delle macchine vapore;* SPAN., *Piezas de máquinas.*

There are many minor contrivances and mechanical appliances attached to steam-engines that require detached and particular investigations both with respect to mechanical arrangement and philosophical investigation. The *details* respecting such subjects we place under the heading *Details of Engines.*

Feed-Pumps.—Simple Forcing-Pump.—The pumps which are in general use, and which are worked directly by the engine, are similar to that of which Fig. 2284 is a transverse section.

A feed-pump acts by overcoming the pressure inside the boiler. This circumstance, together with the small diameter which the pump has in nearly all cases, has led to the adoption of the solid piston, called a *pump-plunger*, or simply *plunger.* (See AIR-CHAMBER, p. 34.) This is the system employed when a high pressure has to be overcome.

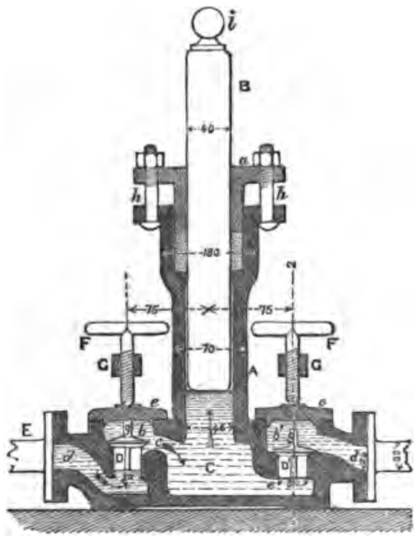
The pump represented in Fig. 2284 consists of a cylinder A of cast iron or of bronze in which works the piston or plunger B. This cylinder is furnished in its upper part with a stuffing-box through which the plunger works. Below the stuffing-box the diameter of the cylinder is sufficiently large to allow the plunger to work freely. The example which we give in Fig. 2284 possesses the peculiarity of being cast in one piece; this is an arrangement that is often adopted, especially when the force exerted is not great. The lower portion of the pump consists of a box or chamber C of an oblong form, the interior of which is divided into two compartments b and b', communicating with the chamber C by means of the clack-valves D and D′, called respectively *sucking* and *forcing valves;* the channels d and d' connect these valves with the pipes E and E′, and with the inner chamber.

It will be seen from Fig. 2284 that in the arrangement adopted for forcing-pumps, the interior of the pump A communicates, on one side, by a lateral opening c with the compartment b, which

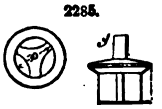
contains the sucking-valve D, and, on the other, by the lower orifice c with the under-side of the forcing-valve D′. And in the same way the suction-pipe E communicates directly by the channel d with the lower side of the valve D, whilst the pipe E′, which leads to the boiler, communicates by the channel d', on the upper side of the valve D′, with the second compartment b'.

It will be seen from the foregoing explanation that when the plunger rises a vacuum will be formed in the chamber C, and the pressure of the atmosphere upon the reservoir will, consequently, force the water in through the pipe E by raising the valve D. When the plunger descends, on the contrary, the force exerted upon the water will close the valve D, and raise the other D′, through which the water will rush by the pipe E′ into the boiler.

2284.



2285.



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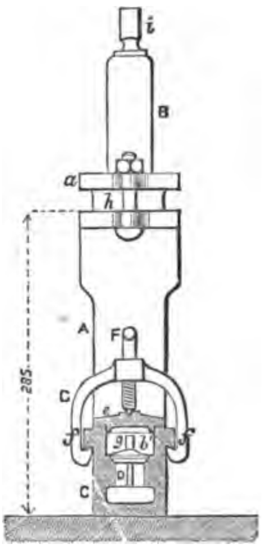

The following details of the example we have chosen will be of use. The form of the valves will be seen from Fig. 2285, which represents one of them in elevation, and as seen from below. They consist of a flat disc with a conical edge to fit the seat, and a cylindrical plug hollowed or fluted on three sides to allow a passage to the water. These valves are adjusted to cylindrical orifices, the upper side of which forms the clack-seat; these orifices are concentric with the compartments b and b', which are also circular and open at the top, to allow the introduction of the valves. When the pump is at work, both of these compartments are hermetically closed by an iron lid e fitting upon a leather or lead washer. As it is necessary to be able to examine the valves easily, the lids e are held down by a single hand-screw F working through the stirrup-piece G, affixed by hooks $f\,f$ to the body of the pump. This arrangement will be easily understood by referring to Fig. 2286, which gives a side view of the pump through a transverse section 1—2 of the clack-box b'.

It will be noticed that each valve has, on its upper side, a short rod g; this rod has several uses. It serves as a handle to turn the valve, or to take it out of its seat; but its chief use is, when the pump is working, to prevent the valve from rising out of the cylindrical aperture in which it moves.

The stuffing through which the plunger plays has nothing remarkable but its simplicity. It consists of hemp, well greased and kept tight around the plunger by the collar a and two belts $h\,h$. This collar is rarely provided with a lubricating cup, as the stuffing is usually greased with tallow, and, as the apparatus works at relatively low temperatures, the grease lasts a considerable time.

We use the term "relatively" because the feed-water is usually warm. But, if the temperature exceeds 30 or 40 degrees Cent., the pump will work badly; and if it be required to heat the feed-water by means of the waste heat, it will be better to effect this operation between the pump and the boiler, that the former may work with cold water only.

The kind of pump which we have described may be of gun-metal or of cast iron. With the exception of the valves, which ought to be of gun-metal or bronze on account of their delicate functions, all the parts should be of the same material. It is the opinion of many experienced men that the presence of different metals in contact with water, the action of which is always in some degree acid or saline, gives rise to a galvanic current which accelerates the oxidation of the metal. We do not assert the truth of this opinion; we mention it as one worthy of attention and requiring further research.

In the case of engines of direct action, feed-pumps are usually worked by means of a circular eccentric placed upon the shaft. A connecting-rod joins the eccentric and the pump-plunger. According to the arrangement shown in Figs. 2284 and 2286, the pump is fixed vertically; but it may be horizontal or inclined, with a slight alteration in the position of the clack-boxes, as we shall have occasion to show later.

Sometimes the feed-pump is connected directly with the motion of the piston of the air-pump,

when there is a condenser; but in that case it is necessary to reduce the diameter of the plunger, because the stroke is relatively considerable. It is true that with the eccentric we may fall into the opposite fault, when we do not wish to give it exaggerated dimensions. This latter condition is, however, more in accordance with the ordinary motion of a pump, which, except in the case of locomotives and engines driven at a high rate of speed, is usually slow. When applied to beam-engines, the pump is worked from the beam, and may have a greatly reduced stroke.

The work of a feed-pump should, like the evaporization, be continuous, but, on account of the difficulty of making it correspond exactly with the loss in steam, it is necessarily intermittent. Besides, as a pump is liable to irregularities, it is needful to give it greater power than theory demands, providing, at the same time, the means of suspending its action at pleasure. This means is furnished by two different methods which do not offer the same advantages.

The first is to put it out of gear, and so to stop it completely. If the mechanism by which this is effected is easily managed, there is no objection to this method.

In the second, the action of the pump is allowed to continue, and the cock in the suction-pipe is partially or wholly closed. This latter method is certainly not the best, for if the cock be closed the pump moves in a vacuum, and if there be the smallest fissure the air will enter. But what is of greater importance is, that this regulating by means of cocks, which are more or less closed while the plunger continues its motion, gives occasion for mistakes which may result in bursting the pipes or some portion of the pump. We have ourselves witnessed a fact of this kind. The connecting-rod which worked the pump belonging to a powerful beam-engine was found to have been twisted, notwithstanding the great diameter of the rod, which was not less than from 4 to 5 centimètres. An accident of this kind must be attributed to the closing of a cock in the forcing-pipe, a circumstance which, in the case we have cited, was rendered more probable by the fact that the driver had the command of cocks on the boiler.

Many methods have been proposed for regulating the feed by means of a pump, by the level of the water in the boiler; few have, however, been adopted in practice.

But whatever method be adopted, accidents may be prevented by providing the pump with a safety-valve. A safety-valve not only prevents accidents, but it may serve to clear the pump of the air which the water always brings in with it, and which is one of the most frequent causes of stoppage. It is well known that when the pump raises the water to a considerable height it produces a corresponding vacuum which disengages the air from the water. The air thus introduced into the pump, ascends to the upper portion, and gradually accumulates till its pressure hinders the sucking-valve from opening. This can be got rid of only by opening a cock placed for this purpose on the pump or by lifting the safety-valve when there is one.

The pump, Fig. 2287, belongs to a two-cylinder engine. It differs from the preceding in the arrangement of the clack-boxes and in being provided with a safety-valve.

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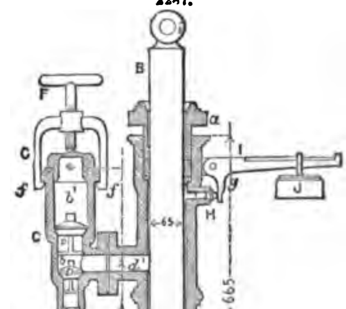

The clack-box is a kind of tube G, independent of the body of the pump and communicating with it by a tubular passage. The inside of the tube C is constructed to receive the two valves D and D′, which are, in this case, one above the other, and unequal in size, as they must be introduced through the same aperture *e*. The suction-tube is in connection with the cock E below the clack-box. A pipe in the portion *b′* of the latter provides the communication with the boiler. When the pump-plunger ascends, the water flows through the passage *d*, forces up the valve D, and enters the pump by the passage *d′* between the two valves. When the plunger descends, the valve D′ is forced up, and the water escapes from the compartment *b′* into the boiler.

It is clear that this arrangement is inferior to those in which the valves are quite free of each other, as in the preceding example. To examine the lower one, it is necessary to remove the upper, and the flow of the water, which changes its direction at each stroke, seems less rational than in the pump represented in Figs. 2284 and 2286.

We come now to consider the safety-valve to which we have alluded. This valve H, of small dimensions, is situated in the upper portion of the pump where the air is likely to accumulate. The valve is loaded by a horizontal lever I, having a projecting piece *g* corresponding to the valve, to which it transmits the action of the weight J.

This valve, which is absolutely necessary to prevent accidents contingent on the ill-timed closing of a cock, or any cause which may hinder the flow of water into the pump, serves also to give egress to the air which is continually accumulating. The conditions of the equilibrium of this valve, as in the case of safety-valves on boilers, have as a basis the internal pressure. The pump-valve must offer an excess of load over this pressure; indeed, it is clear that it may resist this pressure up to the practical limit of resistance of the weakest portions of the pump.

E. Bourdon's Pump, Figs. 2288 to 2290.—The first example is a horizontal pump applied to the horizontal engines constructed by Bourdon for flour-mills at Odessa. These engines are of 25 horse-power. Fig. 2288 is a vertical section, and Fig. 2289 a transverse section along the line 1—2.

The peculiarity of this pump consists in the construction of the clack-boxes and the valves, the latter being hinged. The main or central portion A is provided with two passages *c* and *c′*, exactly symmetrical and terminating in smooth projections. Upon these projections are fixed, by means of screws, two bronze seats C and C′ which have the curved passages *d* and c^2, and the passages

E and E to which are affixed the suction and the forcing pipes. It is remarkable that, according to the natural play of the valves the passage d is in direct communication with the suction-pipe, and the passage d^2 with the channel c', whilst the other channel c is in direct communication with the chamber b.

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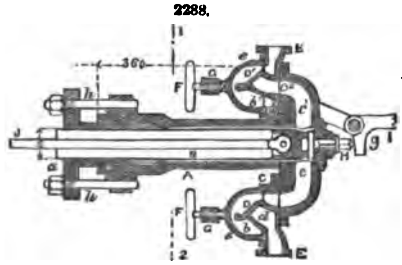

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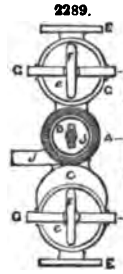

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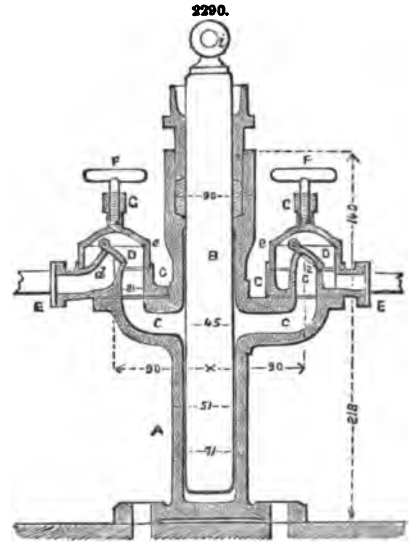

The seats C and C′ are enclosed in bell-shaped covers e, forming the chambers or clack-boxes b and b'; these covers are held in their position by the stirrup-piece G and the screw F. The valves themselves are solid discs fixed by a hinge. It should be remarked, however, that for small dimensions engineers generally prefer the kind described in our first example, which requires less delicate adjustment and which is less liable to get out of order than the hinged valve.

This pump is remarkable for the neatness of its construction and the very rational way in which the water circulates through it, without any sharp angles or changes of direction. The clack-boxes too, being independent of their seats, allow of repairs being easily effected. The body of the pump is of cast iron, but the valves and the boxes are of bronze. With regard to the details of construction, we have to notice that the pump-plunger B is hollow to allow the connecting-rod J, which is jointed to its lower extremity, to work in it; the object of this arrangement being to lessen the length of the whole mechanism without shortening the connecting-rod. This pump is furnished with a safety-valve H of the kind described above. Vertical pumps are fixed by the base; when, as in the present case, they are horizontal, they are fixed by the part j, Fig. 2289, which is cast with them. The bolts h of the collar differ from those of the other examples in having, in the place of the head, an eye which passes over a tenon of the same form, cast with the pump.

Fig. 2288 represents a vertical pump constructed exactly like the preceding one with respect to the valves and boxes. The various parts are marked with the same letters as in Figs. 2288, 2289. When required to perform the same functions as Edwards' pump, this one is evidently far preferable.

We have an important remark to make relative to hinged valves;—Whatever the position of the pump, the position of the valves must be such that they may rest naturally and of their own weight upon their seat, without any assistance from the pressure developed by the play of the plunger. If this be not the case, the play of the valves, which it is always difficult to keep regular, will be faulty, and the pressure of the water will seldom be sufficient to force them back into their places in time. See PUMPS.

Dimensions of Feed-Pumps.—When we know exactly the volume of water requisite to supply an engine, the determination of the dimensions of the pump is only a matter of simple calculation; but as the power of a pump is not strictly limited to the volume of water which is absolutely necessary, the subject demands some consideration.

Volume.—In most steam-engines, the pump-plunger makes as many strokes as the piston; if the circumstances were the same in all engines, the volumes engendered by the piston and the plunger would be proportional, and we might thence determine the proportions of the feed-pump of low-pressure engines. But as each engine may offer particular conditions, such as length of admission and pressure of the steam, it is more rational to endeavour to discover the weight or the volume of water to which each special set of conditions corresponds.

The quantity of water consumed by a steam-engine may vary from 45 to 9 kilogrammes for each horse-power an hour, not including that which, in all cases but in different proportions, is carried off by the steam, but which must be taken into account when it is required to fix the work of the pump. In the presence of variations so considerable as these, it would seem that we should have to assign to feed-pumps as many different proportions as there were different conditions. But it is possible to reduce the problem to more general terms, by remarking, in the first place, that the circumstances in one and the same engine are much less variable when the steam is not used

expansively than when it is so used; and, in the second place, that in the two cases we may bring under two heads engines with and without condensation.

We may thus lay it down;—

1. That an engine in which the steam is not used expansively and which has no condenser, consumes, as a mean, 10 kilogrammes of water in utilized steam, by the horse-power, an hour.

2. That, for an engine in which the steam is used expansively and to which there is no condenser, the power of which engine may vary as much as $\frac{1}{4}$ of the nominal power, and the specific consumption in steam of which is, on the average, 20 kilogrammes, the pump must be constructed for a higher consumption, namely, about 30 kilogrammes.

3. That, for engines in which the steam is used expansively and to which there is a condenser, the power of which engines varies in a similar degree, and the consumption of which varies from 18 to 9 kilogrammes, the mean being about 15, the pump must be constructed for a consumption of from 22 to 25 kilogrammes, by the horse-power, an hour.

If now we modify these quantities, on account of the imperfect working of the pump, which allows us to reckon upon a real production of only 70 per cent. of the volume theoretically engendered by the plunger, and add to them at first 15 per cent. for the possible quantity of water not evaporated, we arrive at the following conclusions;—

High-pressure Engines without Expansion.—The piston or plunger of the feed-pump should engender, as the sum of the single strokes, a volume equal to $\frac{40 \times 1 \cdot 15}{0 \cdot 7} = 65 \cdot 714$, or about 66 cubic decimètres to the horse-power an hour.

High-pressure Engines with Expansion.—In this case the volume will equal $\frac{30 \times 1 \cdot 15}{0 \cdot 7} = 49 \cdot 286$, or about 49 cubic decimètres to the horse-power an hour.

Low-pressure Engines with Expansion.—For this kind we find as the maximum volume to be given to the feed-pump $\frac{25 \times 1 \cdot 15}{0 \cdot 7} = 41 \cdot 071$, or about 41 cubic decimètres to the horse-power an hour.

These numbers, taken as bases of comparison, enable us to compute the real dimensions of the pump, the volume of which is the quotient obtained by dividing by the number of double strokes an hour.

Suppose, for example, that it is required to find the volume engendered by the piston of the feed-pump of a low-pressure engine with expansion, of 25 horse-power and making 30 revolutions a minute, the pump being driven directly, we have $\frac{41 \times 25}{30 \times 60'} = 0 \cdot 570 = 570$ cubic centimètres.

The piston of the feed-pump of M. Bourdon's engine which corresponds to the foregoing data, engenders, by each single stroke, a volume of 630 cubic centimètres.

The work of a feed-pump being intermittent, the supply of water while the pump is at work must be greater than the consumption. The numbers given above are, therefore, only bases, since the capacity of a pump may be increased by this single fact. Sometimes its dimensions are greatly exaggerated in order to be able to obtain from it, in case of need, an excess of work. This is a very pernicious method, and it ought never to be adopted.

Diameter and Length of Stroke.—The diameter and the length of stroke are only an arithmetical deduction from the volume found for a single stroke, and, consequently, have no other interest than the variable relation which may exist between them. The pump-plunger is often driven directly, and gives the same number of strokes as the piston. In this case the length of stroke must be reduced in order that the speed may not exceed a certain limit, beyond which the performance of the pump is bad and the resistances considerable. In fine, it may be said that the diameter and the length of stroke of a pump-piston depend absolutely upon the arrangement of the mechanism, and have no relation that may be established *a priori*. We have only to remark that the speed of the piston should never exceed 50 centimètres a second, and the number of pulsations 100 a minute. For an engine turning at a higher rate of speed than this, a retarded motion should be given to the pump.

Sections of the Valves and the Suction and Forcing Pipes.—In many cases, and especially in the case of engines in which the circumstances are nearly the same, the section of the pump-valves is determined proportionally to the nominal horse-power. It is in this way that we find the section of the injection-tube of the condenser, by taking as fixed bases the height of suction, the counter-pressure, and the greatest specific quantity of water to be injected, for, in this case, the total quantity of water becomes proportional to the nominal power. An analogous method would be applicable to the suction-tube of the feed-pump if the water were free to enter the pump with all the speed due to the vacuum caused by the suction. But it can enter only in virtue of the space allowed by the plunger, the speed of which is, as we have seen, very restricted; we must, therefore, take this speed as a starting-point, employing as a basis the mean volume of water assigned above to the three different kinds of engines respectively.

It may be admitted that the speed of the water through the suction-tube is, on the average, $0^m \cdot 50$ a second; but as the play of the pump is intermittent, we may put it at a continuous rate of $0^m \cdot 25$ a second. Applying this method to the three kinds of engines, the volumes of water for which have been calculated above, we obtain the following results;—

High-pressure Engines without Expansion.—We have seen that the feed-pump of this kind of engine ought to supply 40 kilogrammes, or litres, of water to the horse-power an hour, plus 15 per cent. for the water carried off by the steam. The section of the suction-valve of this pump, according to this, is equal to the dimensions expressed in square decimètres, $\frac{40 \times 1 \cdot 15}{2 \cdot 5 \times 3600} = 0^d \cdot 00511$, or about $\frac{1}{2}$ a square centimètre to the nominal horse-power.

High-pressure Engines with Expansion.—Operating in the same way for this second kind, we find as the section of the suction-valve $\frac{30 \times 1 \cdot 15}{2 \cdot 5 \times 3600} = 0 \cdot 00383 = 0 \cdot 383$ square centimètre to the horse-power.

Low-pressure Engines with Expansion.—We obtain in the same way,

$$\frac{25 \times 1 \cdot 15}{2 \cdot 5 \times 3600} = 0 \cdot 00319 = 0 \cdot 319 \text{ square centimètre.}$$

These proportions are in accordance with those adopted in practice, though they cannot be regarded as *invariable rules;* they should be used as a point of comparison, in order to be sure of not going below their value, which, on the contrary, may be exceeded without inconvenience, if the general proportions of the pump will allow it.

To give our readers a clear apprehension of the method of applying these proportional bases, we will give an example.

Example.—What ought to be the least section of the suction-valve of the feed-pump, applied to a low-pressure engine, with expansion, of 25 horse-power.

The specific section being $0 \cdot 319$ square centimètre, we find for the power proposed,

$$0 \cdot 319 \times 25 = 7 \cdot 98 \text{ square centimètres.}$$

This section corresponds to a circle of about 32 millimètres in diameter, which is the size to be given to the suction-tube; as to the valve itself and its seat, it should have dimensions which give an equivalent effective orifice, on taking into account its nature and arrangement. We repeat that an advantage will be gained by increasing the dimensions thus found, when the construction will allow it.

It is supposed in the preceding rule that the height of suction is always much less than that which would allow the water raised only an initial velocity, in the ascension pipe, of 50 centimètres a second.

Taking a height of 5 mètres as a maximum, the water would have, on this condition, a tendency to escape through the orifice of the valve with a velocity always equal to

$$v = \sqrt{19 \cdot 62 \times (10^{m} \cdot 33 - 5^{m})} = 10^{m} \cdot 21 \text{ a second.}$$

It is customary to give to the forcing valve and pipe the same dimensions as to the suction valve and pipe, in which case the water acquires through them the same mean velocity. We have only one objection to make to this, namely, the pressure being much greater, and the pipe being often of considerable length, the resistance is greatly increased, and thus the chances of rupture are multiplied. Consequently, while giving to the forcing-valve the same dimensions as to the other, it would be prudent to increase slightly the diameter of the pipe, especially if it be long, in which case the resistance is augmented. It must not be forgotten, too, that the section of these passages is reduced in course of time by the deposit of matter brought in by the water, and which is suspended in it, or in a state of calcareous dissolution.

Of even greater importance is the avoiding of sharp angles, almost doublings, which are sometimes given to this kind of pipe under the pretext of hiding them in the masonry in which they are built. By such faults as these, the section of the forcing passage is often so much reduced that the slightest accidental obstruction may cause the bursting of the pipe, or of some portion of the pump.

Self-acting Feed Apparatuses.—Feed-pumps rarely work with sufficient regularity to render it unnecessary to watch their performance. With a pump of small dimensions, without a reservoir of air, and moving at a considerable speed, it will often happen that the valves either get out of their seats or close imperfectly, this latter circumstance arising from the interposition of pieces of gravel brought in by the water. Often, when the pump has been stationary for a considerable time, it will not work till the clack-boxes have been filled with water.

This uncertainty in the working of pumps, added to the difficulty of making their production correspond with the evaporization, which may be increased without accelerating the speed of the engine and the pump, has led engineers to seek methods of regulating the supply of water by the level of the water in the boiler. One method of effecting this offers itself almost naturally to the mind.

Suppose, in communication with the boiler, a tube of sufficient height to put the water it contains in equilibrio with the pressure of the steam. If this column of water be in communication with a reservoir by means of a floating valve, it is clear that this column, having a tendency to sink with the level of the water in the boiler, will supply at its base the volume necessary to maintain it while receiving an equal quantity from the reservoir above. Here, then, we have an apparatus that would evidently work well in theory.

But this tube must have in height as many times $10 \cdot 33$ mètres, minus one, as the steam has atmospheres; consequently, even for a fixed high-pressure engine, the method is almost impracticable. It has been employed, however, but only when the pressure has been slightly above that of the atmosphere; in this case the column of water may be of a somewhat limited height. We will give an instance of one of these, before we attempt to discuss some of the inventions for high-pressure engines.

Fig. 2291 represents the apparatus applied to a boiler; it is the same as that applied to most low-pressure engines on Watt's system, and is composed of a column A, of about 3 mètres in height, fixed to the boiler B with which it is in free communication by the tube C. The water in it, consequently, rises to a height corresponding to the excess of the pressure of the steam above that of the atmosphere.

The pressure in these boilers being at $1 \cdot 2$ atmosphere, or about $\frac{1}{5}$ above the surrounding atmosphere, it follows that the column of water will stand at a height of about 2 mètres above the

level in the boiler, or about the fifth of a column of water in equilibrio with a pressure of one atmosphere.

This column is terminated in its upper portion by a cistern D, the bottom of which is formed of a piece E, shaped like a reversed funnel, the use of which we will explain farther on. This bottom is pierced with a small aperture provided with a conical valve or plug F, suspended by a rod *a* to a lever G resting on the side of the cistern; one of the ends of this lever is attached to a rigid rod *b* entering the boiler through a tube H which plunges freely into the water; this supports a float I of a circular shape on account of the tube H, and of a density greater than that of the water. The other end of the lever G supports a counterpoise *c*, to balance the float. It must be remarked that the tube H, in which the water of the boiler rises to the same height as in the principal column, has no other use than to render a stuffing-box for the passage of the rod *b* unnecessary.

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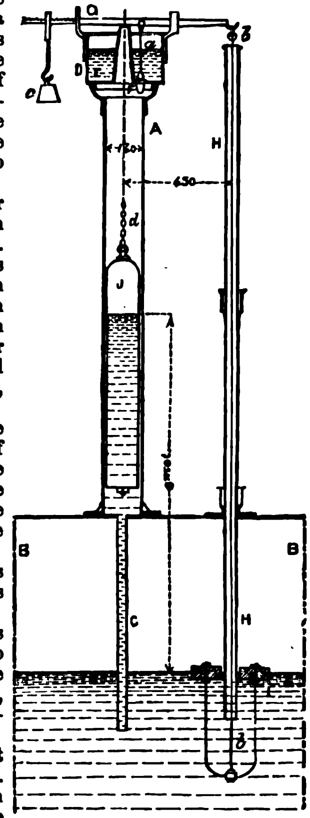

When the water-level in the boiler is at its normal point or above, the float I will not descend, and the valve F being held in its seat, the water in the cistern D cannot get into the column A. If the level sinks, on the contrary, the float follows it and lifts from its seat the valve F which allows the water in the cistern to escape. This water being added to that of the column which is in equilibrio with the pressure, and the height of which can vary only with the pressure, it follows that a quantity of water equal to that escaping from the cistern enters the boiler and raises the level to its normal point. The height being restored, the float ascends and closes the valve F.

This apparatus may be connected with the register of the chimney in the following manner. A float J upon the column of water, is attached to the chain *d* which passes through the orifice in the piece E, and is fixed at the other end to the register. The column in the tube A varying in height with the pressure in the boiler, the register will be opened or closed by the fall or rise of the float J.

Fig. 2292 is the pump belonging to the same engine, and is used to lift the water to the apparatus described above. It differs from other feed-pumps in being *lifting* instead of forcing.

This pump has only a small force to overcome, since its piston supports only the weight of a column of water equal to the vertical distance from the pump to the feed-head, a distance of about 5 mètres, or ½ atmosphere instead of 5 and upwards, which the force-pumps of high-pressure engines have to overcome.

The body of the pump A is open at its lower extremity. It is bolted to the box B in which are the clack-valves D and D′. The suction-valve D is placed over a pipe C in communication with the tank receiving the hot water from the condenser. The box of the second valve D′ communicates by a tubular passage E with the pipe leading to the feed-head.

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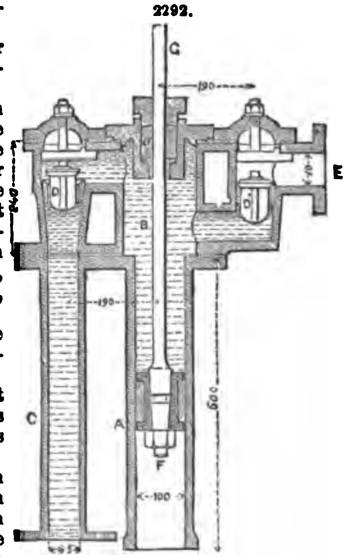


This kind of pump is now little used, because the water is sent directly into the boiler, and for this purpose a forcing-pump is better adapted.

Apparatus for High-pressure Engines.—We have shown above the principle of self-acting apparatus, and we have seen that it may be easily realized when the pressure in the boiler exceeds but little that of the atmosphere. But for higher pressures other means have been resorted to, the simplest of which we will explain. It is right to add that these various arrangements have been attempted more especially in the case of boilers that are not designed to furnish steam to an engine, as in this latter case a pump may be used, and unless the method of the pump could be improved upon, there was no necessity for resorting to other means.

There is also apparatus working in conjunction with the pump, and designed to regulate the quantity of water introduced, by the level of the water in the boiler.

Feeding-vessel.—This very simple apparatus works without a pump and under all pressures; it is employed for boilers used for heating purposes, or for any purpose where steam is required without an engine.

It consists in principle, as may be seen from Fig. 2293, in placing above the boiler a vessel A containing a certain volume of water, which vessel may be put in communication with the boiler B, by two pipes C and D, one entering above the surface of the water in the vessel A, and the other below.

The first pipe C goes from the steam-chamber to the upper portion of the receptacle A; the

second D goes from the lower portion of the same vessel to near the level, and in some cases below the level of the water in the boiler. These two pipes are provided with cocks *a* and *b*; when it is required to introduce water into the boiler, the first cock *a* is opened, and the steam entering the vessel A, exerts its pressure upon the water. The second cock *b* is now opened, and both surfaces being subjected to an equal pressure, the water will flow from the vessel into the boiler in virtue of the difference of height of the two levels. When sufficient water has flowed into the boiler, the cocks are closed and the feeding suspended.

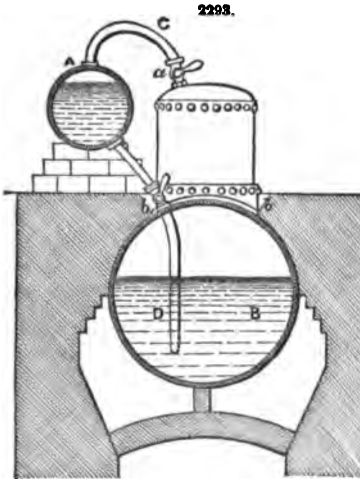
It will be remarked that this operation requires the intelligent care of a man. But it may be made self-acting by means of a contrivance based upon the principle of floating valves, which is sometimes done.

The lower end of the pipe D may be above or below the level of the water in the boiler; it is, however, preferable to place it below to avoid the boiling caused by the steam which would endeavour to force itself into the pipe if it opened into the space occupied by the steam. But in this case the cocks must be carefully managed; for if the cock *b* were opened before the pressure had fully exerted itself in the vessel A, the water from the boiler would rush up into it, instead of the opposite effect being produced.

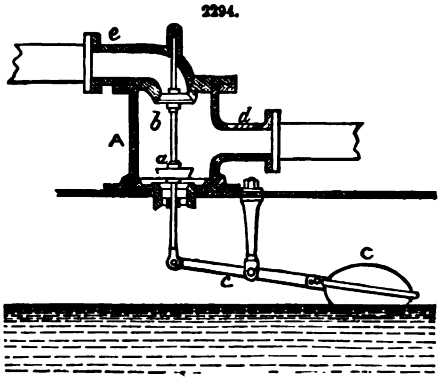
We have supposed that the feeding bottle was itself supplied with water by hand, before setting it in operation, and for a determinate time. But this vessel may be made to feed itself in the following manner;—

A pipe provided with a cock puts it in communication with the reservoir; then a jet of steam is let into the vessel, which steam, by first expelling the air, and then being itself condensed, causes a vacuum which the water in the reservoir will rush up to fill. Of course, this method is practicable only when the vessel is not situated at too great a height above the reservoir.

2293.



2294.



Regulator working in conjunction with a Pump.—The apparatus represented in Fig. 2294 has also been employed to regulate the introduction of the feed-water supplied by a pump working continuously. It consists of a cylindrical box A of cast iron or of bronze, placed upon the boiler B with which it communicates by the valve *a*, the rod of which is connected with a float C fixed to one end of the lever *c*. This box is closed at the top by a tubular cover *e*, the inner orifice of which is provided with a valve *b*, upon the same rod as the valve *a*, but turned in the opposite direction, so that one closes when the other opens.

The box A is in free communication with the feed-pump from which the water enters by the tubular passage *d*, situated between the two valves. The pipe *e* takes the water back to the reservoir.

When the valve *a* rests upon its seat, the other will be withdrawn, and the box *a* will be in communication with the pipe *e*. In this position, the water which is constantly supplied by the pump will not enter the boiler, but, passing through the valve *b*, will pass back to the reservoir through the pipe *e*. If, on the contrary, the valves are in the opposite position, the water will flow only through the valve *a*, and will thus reach the boiler.

If we could rely upon the regular working of the float, such an apparatus would be perfect. But any derangement of its mechanism, capable of hindering wholly or in part the play of the valves, is of serious consequences, since the several parts are out of sight, and to remedy the fault it is necessary to stop the boiler and to allow it to become sufficiently cool.

Higginbotham and Gray's Apparatus.—This apparatus is founded upon the principle of the contrivance called a cataract, which, as is well known, utilizes a constant flow of water to produce intermittent actions by a cock or a valve.

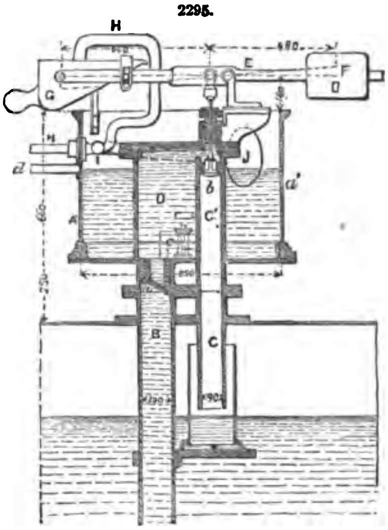
It consists of a box A, Fig. 2295, placed on the top of a piece with two pipes B and C which descend into the boiler. The pipe B descends nearly to the bottom of the boiler, and communicates with a separate compartment D, inside the box A. The communication may, however, be intercepted by a clack-valve *a* closing from the force of an upward pressure. The other pipe C opens into the space occupied by the steam, and ascends by a continuation C′ in the box A, or

rather in the interior of the compartment D, with which it communicates at the top when the other valve b, which opens downwards, is lowered.

Before explaining the action of the cataract, the work of which is to close or open this latter valve, let us see more in detail the arrangements which enable the water to enter the boiler.

The box A is filled with water which may pass in part into the compartment D, by raising a third valve c, shown in the figure by dotted lines.

2295.



Suppose this valve closed, the valve b open, and the compartment D partly filled with water. The steam introduced through the passage C will enter the compartment D, and exerting its pressure upon the water therein contained, the same effect will be produced as that explained above in reference to the feed-bottle; both surfaces being equally pressed, the water will flow into the boiler by opening the valve a.

If now the valve b be brought down upon its seat, the steam which occupied the upper portion of the compartment D, being cut off from its source, will be condensed, leaving a vacuum, the double effect of which is to close the valve a by the predominant pressure in the boiler, and to open the bottom valve c by the action of the atmosphere which presses constantly upon the water in the receptacle A. A portion of the water contained by the receptacle A will therefore pass into the compartment D.

To complete the description of this ingenious contrivance, it remains only to explain the method by which the valve b, the prime mover of the whole system, is opened and closed at the proper times.

This valve b is connected with the balance E, having its point of oscillation above the compartment D. One end of the balance is provided with a weight F, and the other supports a kind of box G, triangular in section, and capable of outweighing, according to its point of suspension, the end F. A pipe H leading from a reservoir pours its water into the box G. The pipe has a cock I, connected with the arm of a float J, which rises and sinks with the level of the water in the receptacle A.

If we take the mechanism in the situation in which it is represented by the figure, the water flows into the vessel G, which is now outweighed by the weight F, a state of things that keeps the valve b closed. But the flow through the pipe H continuing, the vessel G is soon sufficiently filled to overcome by its weight the counterpoise F and the pressure of the steam against the valve b. It therefore sinks, carrying with it the lever E, and giving rise to several simultaneous actions, which, for the sake of perspicuity, we will indicate separately.

1. The valve b is removed from its seat, to allow a passage of water into the boiler, under conditions described above.

2. The vessel G strikes against the edge of the receptacle A, and pours into it the water which it contained.

3. The water thus received into the receptacle raises the level, and with it, of course, the float J, which, in its turn, closes the cock I and stops the flow of water through the pipe H.

4. The vessel G being empty is outweighed by the counterpoise F; the lever E ascends; the valve b is brought up to its seat, and the work of feeding the boiler is suspended.

From what has already been said, it will be seen that the closing of the valve b causes the water to pass from the receptacle A into the compartment D. The level in A being thus reduced, the float J sinks, the water again flows through the pipe H, and the same actions are repeated.

With respect to the length of the intervals between these various occurrences, we see that the time during which the valve b is open is fixed, since it can last only while the vessel G is pouring out its contents. Consequently, the introduction of water into the boiler is effected in equal quantities. And the interval between each of such introductions must evidently depend upon the time required to fill the vessel G. Thus the total quantity of water furnished may be varied by means of a cock or other contrivance upon the pipe H.

It is important to remark, that if the level of the water in the boiler rises above its normal point, on account of a slower production of steam, or by an excess of supply, the introduction of a fresh supply will cease as soon as the level has reached the lower end of the pipe C.

It is evident that in this situation, the steam being unable to reach the top of the compartment D, no flow of water can take place between it and the boiler; but the play of the vessel G still continuing, the water thus supplied to the receptacle A flows off through a pipe d provided for this purpose.

This apparatus is suited to all pressures; but it does not seem capable of utilizing feed-water of a high temperature relatively to that of the steam, the condensation of which, in the compartment D, should, in the matter of rapidity, be in a direct ratio with the play of the vessel G, to allow the proper introduction of the outer water into this compartment D.

Self-acting Feed Regulator.—This invention is a very ingenious one and likely to produce safe results.

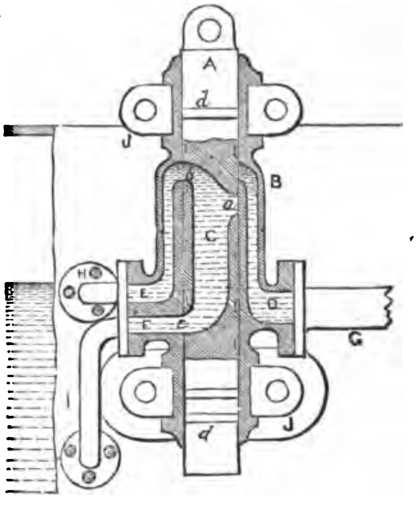
Fig. 2296 represents one of the many arrangements of which this apparatus is susceptible.

The inventor characterizes the principle as "a volume of water in a changed medium;" that is, taken from the surrounding atmosphere and introduced into a new medium in which the inner pressure of the boiler prevails, a medium from which the water may freely flow into the boiler as

that therein contained becomes exhausted; the fluctuations of the level in the boiler thus being the motive and regulating cause of the supply.

As shown by the figure, the instrument consists of a bronze case B, fixed on the outside of the boiler, in which case moves a cylindrical piece A passing through it. This piece, which forms a kind of register, is the *measurer* or moving receiver of the apparatus; it is subjected to a rectilineal, reciprocating motion, like a piston or a valve the functions of which it discharges simultaneously.

2296.



On each side of the central aperture in which the register works there are two channels D and E opening into it. D communicates with a pipe G leading to the reservoir of feed-water which is placed a little above the apparatus; E communicates with a tube H opening directly into the boiler, *at the height at which the level is to be maintained.*

A third channel F communicates with a pipe I which opens into the boiler at a certain distance below the normal level.

The piston-valve A is provided with a cavity C pierced with three orifices *a*, *b*, and *c*. The orifice *a* is on the same side as the pipe D from the reservoir; *b* and *c* are on the opposite side and at a distance apart equal to that of the orifices of the channels E and F, with which they must correspond when the piston is in the lower position, whilst in the opposite position the orifice *a* coincides with the mouth of the channel D.

The reciprocating motion of the piston produces the following effects.

The water from the reservoir, flowing continuously through the channel D, fills every part of the apparatus, including the pipes H and I, and taking as an example the position represented in the figure, that is, the piston A at the end of the stroke, the water contained in the apparatus is in free relation with the boiler the pressure of which it supports, whilst its communication with the reservoir is cut off by the orifice *a* sinking below that of the channel D. In this position, water may flow into the boiler, but only on the condition that *the level in the boiler is* BELOW *the mouth of the pipe H;* otherwise no drop of water can pass from the apparatus.

If the mouths of the pipes H, I, are covered by the water in the boiler, which transmits the pressure of the steam, the water contained in the apparatus is in the same condition as mercury in a barometrical tube which is too short to be in equilibrio with the pressure of the atmosphere; the tube would in this case be completely filled with mercury, which, instead of flowing out, would be driven up to the top of the tube.

But when the level sinks sufficiently to *uncover* the mouth of the pipe H, the steam dividing the liquid column may reach the top of it, and exerting its pressure above the mass contained in C, the water will be in a medium of equal pressure, and will flow through the pipe I under the influence of its initial height, from *b* to E.

It follows from this arrangement, that the apparatus, though constantly in communication with the reservoir, will not allow any water to enter the boiler till the level sinks below its normal point; but when this is the case each stroke of the piston may send into the boiler all the water contained in the apparatus, a quantity that is replaced by the reservoir when the piston reaches the other end of the stroke and brought the orifice *a* opposite that of the channel D.

Here, then, we have an ingenious instrument capable of self-action, certainly infallible, and requiring no valves or cocks of any kind. Without stopping its action for a moment, no atom of water can pass into the boiler while the level is at its normal point, but as soon as the level sinks in the smallest degree below this point, a fresh supply brings it back to its former position.

In applying this apparatus to a boiler, it is desirable to place the injection-pipe in that part of the boiler where the water is least agitated, which, in the case of fixed engines, will be the part farthest from the furnace. In the case of locomotives or steam-vessels, the pipes H and I may be made to communicate with a receptacle placed on the outside of the boiler and forming a kind of water-level, the transverse section of which, being small, would render less sensible the accidental oscillations of the general level. These are details of practice that may be easily contrived.

As to the details of the model represented by the figure, they require only a passing notice, as the apparatus is merely one of principle, and far from being a definitively chosen arrangement.

The piston A, though turned very exactly to fit the aperture in which it works, is provided on each side of its orifices with an elastic band or washer *d* to prevent any escape. The reciprocating motion may be communicated to it in several ways. But as the passage of the water from the reservoir into the apparatus, or from the apparatus into the boiler, takes place at the ends of the stroke, the piston should rest a moment in that position. This might easily be effected.

The parts marked J in the figure are those by which the apparatus is fixed to the boiler.

Section of the Injection-Tube for Condensers.—We have based our calculations of the section of the injector and the air-pump of condensers upon the following Table.

This Table shows, as we might, indeed, have foreseen, that the quantity of water to be injected for the purpose of effecting condensation in the same final conditions *decreases* as the initial pressure increases and as the expansion is prolonged. The proportional weight of cold water to that of steam expended increases, however, with the pressure, and, as the last column of the Table shows,

26 times its own weight of cold water is needed to condense steam at 1 atmosphere, a proportion that becomes 27 for 7 atmospheres.

TABLE OF THE QUANTITIES OF COLD WATER REQUISITE FOR CONDENSATION, THIS WATER BEING TAKEN AT 12°; THE CONDENSING WATER RAISED TO 35°; AND THE RATIO OF THE USEFUL TO THE THEORETICAL WORK OF THE STEAM BEING 50 PER 100.

Pressure in atmospheres.	Weight of Cold Water to be injected to the horse-power an hour, in kilogrammes.								Ratio of the weight of the Water injected to that of the Condensed Steam.
	Full pressure.	Admission $\frac{1}{2}$	Admission $\frac{1}{3}$	Admission $\frac{1}{4}$	Admission $\frac{1}{5}$	Admission $\frac{1}{6}$	Admission $\frac{1}{8}$	Admission $\frac{1}{10}$	
1	895	539	447	405	382	369	353	350	26·18
2	812	487	394	352	325	309	288	275	26·45
3	764	459	374	332	305	289	265	252	26·52
4	749	446	361	321	294	275	254	240	26·76
5	737	438	355	314	287	269	247	231	26·90
6	724	431	347	307	283	264	242	226	26·92
7	713	421	343	302	278	259	238	223	27·00

To show the use of the above Table, let us consider the following question. What quantity of cold water is required for purposes of condensation in a fixed engine of 30 nominal horse-power, the pressure being 5 atmospheres and the degree of expansion 6 to 1?

The Table gives, for these conditions, 269 kilogrammes to the horse-power an hour; which makes for 30 horse-power, $269 \times 30 = 8070$ kilogrammes or litres an hour.

Thus we have to the second $\frac{8070}{3600} = 2 \cdot 241$ litres.

And for a day of 12 hours, $8070 \times 12 = 96840 = 96 \cdot 840$ cubic mètres.

This volume of water is considerable, and shows the necessity of considering the capabilities of a place in this respect, before having recourse to a condensing engine.

The water is injected into the condenser through the mouth of a pipe which plunges directly into the tank, or which simply communicates with a reservoir fixed at the same height as the condenser.

Though there is no reason why an excess of section should not be given to this pipe as well as to the ajutage at the end, and the supply be regulated by a cock, it is none the less profitable and interesting to consider the *minimum* of this section.

When the pipe plunges directly into the tank, the velocity with which the water will be injected into the condenser will depend on the difference of the pressure of the atmosphere and the sum of the counter-pressure added to the height of the suction. When the water has been previously raised to the height of the condenser, the initial pressure is that of the atmosphere diminished by the counter-pressure.

In the former of these two conditions, the height at which injection would be impossible may be easily foreseen; it is the same as for an ordinary pump. Not only must this limit never be reached, but at a height which would render the work of suction doubtful the water must be raised by means of an auxiliary pump.

To deduce the minimum section of the injection-pipe, let us assume 5 mètres to be the maximum height of suction and $\frac{1}{4}$ atmosphere the extreme of the counter-pressure.

The velocity with which the water will be injected into the condenser, under these conditions, will be (see Armengaud's Treatise on Hydraulic Motors),

$$v = \sqrt{19 \cdot 62 \times (10 \cdot 333 - 5^{m} - 2 \cdot 667)} = 7^{m} \cdot 23 \text{ a second.}$$

The greatest quantity given in the preceding Table is 895 litres to the horse-power an hour, say, in round numbers 900, which gives to the horse-power a second $\frac{900}{3600} = 0 \cdot 250$ cubic decimètre, or 250 centimètres. Dividing this cube by the above velocity, expressed in centimètres, we have for the section sought $\frac{250}{723} \doteq 0 \cdot 345$ square centimètre to the horse-power. Thus for an engine of 20 horse-power, the minimum theoretical section of the injection-pipe, for the given height, will be $0 \cdot 345 \times 20 = 6 \cdot 9$, say 7 square centimètres. But to retain the necessary latitude, and to compensate the loss occasioned by friction and by the contraction of the terminal ajutage, the section of this pipe, supposed straight and of the same size throughout, should be, at least, doubled; the preceding example would, therefore, give 14 square centimètres, corresponding to a diameter of 42 or 43 millimètres.

Having taken as a basis the greatest quantity of water to be injected to the unit of power, the extreme counter-pressure and the height of suction beyond which it becomes necessary to raise the water by means of an auxiliary pump, it seems that we may admit, as a rule applicable to every case,

That the section of the injection-pipe should be practically fixed at 0·7 square centimètre, or 70 square millimètres to the actual horse-power, taking as a basis the greatest useful power which the engine is capable of developing.

These dimensions are adopted by many engineers of the present day.

Dimensions of the Air-Pump.—The considerations concerning the injection-pipe of the condenser,

and the Table on which those considerations were based, enable us to determine the dimensions of the air-pump; and in our following remarks the references must be understood to be to that Table.

The function of the air-pump, as is well known, is to withdraw continually from the condenser not only the water injected with that arising from the condensing of the steam, but also the air which is evolved from it. This latter element is the most difficult to determine; but as the power practically given to the pump exceeds by much the result found by approximation, we may content ourselves with a rough estimate.

It is known that water, at the usual temperature and pressure of the atmosphere, absorbs about $\frac{1}{14}$ of its volume of air or gases in the condenser, in which we will suppose the pressure to be $\frac{1}{10}$ of the atmosphere, and the temperature from 35 to 38 degrees. The disengaged air expands under the double influence of the diminution of pressure and the increase of its temperature, which would then be 23 degrees, rising from 12 to 35.

Proceeding upon this hypothesis by means of the formula for the expansion of gases, we find that the volume of air to be extracted by the pump is equal to about $\frac{6}{10}$ of that of the water. But if we take into account the volume of steam mixed with the air and of an equal volume, we must consider the total volume of gases to be extracted as approximatively equal to $\frac{16}{10}$ of that of the water injected.

Denoting by P′ the weight of the water injected, and by P that of the corresponding quantity of steam to be condensed, the total quantity of water which the pump will have to extract, at each single stroke of the steam-piston, is $P' + P$, consequently $P' + \frac{P'}{27} = \frac{28}{27} P'$. As with water, the density of which is taken as unity, we may take the weight for the volume, that is substitute here V for P′, we may say, taking into account that of the air above, that the total volume to be extracted by the pump at a single stroke of the driving piston is equal to $\left(\frac{28}{27} + \frac{16}{10}\right) V = 2{\cdot}64\, V$.

Thus, admitting this theoretical number, when we have to inject into the condenser in a given time 300 kilogrammes or litres of water, the air-pump should engender, as a minimum, in the same time a volume of 792 litres.

If now we wish to determine the proportion between this volume and that engendered by the driving piston, we see at once that it is essentially variable, since we have taken as a basis the actual volume of steam expended, which changes relatively to that of the cylinder, according to the degree of expansion employed. To determine the principal limits of this proportion, we will take those which in the Table indicate the weights or volumes of the condensing water for 1 atmosphere with full pressure, or no expansion, and for 7 atmospheres with admission $\frac{1}{10}$.

For the former of these two conditions giving 895 litres of condensing water, the preceding rule gives, as the volume of the air-pump, $2{\cdot}64 \times 895 = 2363$ litres nearly.

But for these conditions, Armengaud has shown that the driving piston should engender 58066 litres; the ratio of these two volumes is, therefore, $\frac{2363}{58066} = 0{\cdot}04$. That is, the theoretical volume of the air-pump would be only $\frac{1}{25}$ of that of the cylinder.

Passing on to the second case, admission $\frac{1}{10}$, pressure 7 atmospheres, which corresponds to 223 litres of injected water, and to 23626 for the volume of the cylinder, that of the pump would be $2{\cdot}64 \times 223 = 589$ litres; and its ratio to that of the cylinder $\frac{589}{23626} = 0{\cdot}025$.

In this latter case, the volume engendered by the air-pump will be only $\frac{1}{40}$ of that of the cylinder; and if we had chosen an example with a small pressure and a great expansion, the result would have been smaller still.

It follows from the preceding that the air-pump, like the condenser, should be proportionate, not relatively to the absolute volume engendered by the whole stroke of the steam-piston, but by taking as a basis the volume of steam expended at full pressure. It now remains to see what correction should be made in the preceding theoretical proportion.

Hitherto we have admitted a vacuum in which the pressure was at least $\frac{1}{10}$ of the atmosphere; but if $\frac{1}{20}$ be reached, a result which some have endeavoured to bring about, the gases to be abstracted will acquire a double volume, say $\frac{32}{10}$ V, which, added to that of the water, gives for this total volume $\left(\frac{28}{27} + \frac{32}{10}\right) V = 4\, V$ nearly.

If, as Watt did, we double this product, to provide for the imperfect working of the pump, and for the possible increased power required of the engine and obtained by a lengthened admission or an augmented initial pressure, we shall have the following simple rule;—

The useful and effective volume engendered by the air-pump should be equal to 8 *times that of the cold water injected.*

This rule may be taken as a safe guide, but it must not be regarded as resolving the problem in an absolute manner, for an engine is never constructed to develop always the same power, with the same degree of expansion and the same initial tension; and the volume of the pump, which is invariable, should be determined by the mean power which the engine is capable of producing.

To compare the results of this rule with the usual data, we will consider two examples.

First Example.—To find the volume of the air-pump for an engine working without expansion with steam at 2 atmospheres, the ratio of the useful to the theoretical effect being $\frac{50}{100}$.

In this case, Armengaud gives 27·541 cubic mètres as the volume engendered by the steam-piston to the horse-power an hour.

The Table gives as the quantity of water to be injected 812 kilogrammes.

The effective volume, to the horse-power an hour, of the air-pump will, therefore, be according to the proposed rule, $112 \times 8 = 6496$ litres or cubic decimètres.

Comparing this volume with that of the cylinder, we find $\frac{6496}{27551} = \frac{1}{3 \cdot 1}$.

This pump will thus have very large dimensions comparatively to the cylinder, for if it is of a single stroke, its volume a stroke will be about $\frac{1}{3}$. This excess is explained by the fact that the rule is established for a much more complete vacuum than was obtained in old condensing engines without expansion.

Second Example.—Solve the same problem for an engine working with $\frac{8}{10}$ expansion and 4 atmospheres.

The specific volume of the cylinder is, according to the same authority, 42·789 cubic mètres.

The quantity of water to be injected is 240 kilogrammes or litres; the volume engendered by the pump-piston equals $240 \times 8 = 1920$ cubic decimètres.

Ratio of the two volumes $\frac{1920}{42789} = \frac{1}{22 \cdot 3}$

This time the pump would be much less powerful than that usually made. But an engine, the nominal power of which is regulated by the exceptional admission of $\frac{1}{10}$, ought to give in a case of need the double of this power, by increasing the length of admission to $\frac{1}{4}$ of the stroke of the piston.

Consequently, this ratio would by this only be reduced to one-half, since the quantity of steam expended, and as a consequence that of the water injected, is doubled. But for $\frac{1}{4}$ admission and 4 atmospheres, the quantity of water to be injected is, according to the Table, 294 litres, whence the volume to be practically adopted for the pump becomes $294 \times 8 \times 2 = 4704$ cubic decimètres.

And its ratio to that of the cylinder assumes this last value, $\frac{4704}{42789} = \frac{1}{9}$ nearly.

We have nothing to add to these examples, which show clearly how the rule we have laid down is to be used—a rule that is at once conformable to the proper working of the pump and the exigencies of practice.

Dimensions of Steam-Ports.—Induction and Eduction Pipes.—Section of the Orifices of Induction and Eduction.—The dimensions of the pipes and orifices traversed by the steam in passing from the boiler to the cylinder, and of those through which it escapes into the atmosphere or into a condenser, is a matter which has not always been sufficiently considered, and which, even at the present day, when the construction of steam-engines is pretty well understood, is somewhat neglected by builders.

This question, considered on purely theoretical grounds, would be an extremely complicated one; but we are now in possession of practical results which enable us to solve it in a very simple way and with a high degree of certainty. We shall, therefore, confine ourselves to a general examination of the facts which accompany the circulation of the steam when on its way to the cylinder, or when escaping from it, and to a simple exposition of the principles by the aid of which we are enabled to determine the proper dimensions of the passages through which it flows.

Communication between the boiler and the cylinder is provided by means of a pipe, circular in form, leading from a cock on the boiler to the steam-chest, through which the steam is allowed to flow in regular quantities by means of certain valves.

If we suppose, for a moment, that these several regulators offer a passage to the steam, and have all an aperture equal in section to that of the pipe, the steam will flow into the cylinder with a velocity easily calculated. If there be no sharp angles, this velocity will be constant throughout the distance, and if the pressure in the boiler be considerably greater than that in the cylinder, it may reach several hundred mètres a second.

To enable us, however, to form an idea more in accordance with fact, we must remark that at the moment when the steam begins to flow into the cylinder, the piston, which is at the beginning of its course, is set in motion with a velocity immeasurably less than the initial velocity of the steam. Consequently, the space left vacant above it is soon saturated, and an equality of pressure with the boiler being theoretically established, the flow of the steam can take place only with the advance of the piston, with a velocity, in the steam-pipe, in inverse ratio with its section and that of the cylinder.

Suppose, for example, that the piston moves with a mean velocity of 1 mètre a second, and that its superficies is twenty times that of the steam-pipe, the steam will flow through the latter with a velocity of only 20 mètres a second, instead of from 300 to 500 mètres and more; it will acquire from 1·5 to 5 atmospheres, by flowing in a medium the pressure of which was constantly 1 atmosphere. In a non-condensing engine, we may consider as such the medium in which the steam flows, for the piston is nothing but a diaphragm interposed between it and the surrounding atmosphere.

It follows from this that, if the circuit of the steam were of very small extent, and without sharp angles or other impediments, a pipe having a very small section would be sufficient, since the steam is required to move through it with a velocity very much less than it is capable of acquiring in these conditions.

Let us suppose, for example, the lowest pressure of 1·5 atmosphere, no condensation, and, for the piston, the high velocity of 3 mètres a second. The velocity of the flow of the steam into the atmosphere, under this pressure of 1·5 atmosphere, is equal to 343 mètres. Consequently, the section of a steam-pipe, perfectly uninterrupted and very short, might be reduced, as a minimum, to the following fraction, $\frac{3}{343} = \frac{1}{114}$ of the surface of the piston, below which value the space would no longer be *saturated*. The conditions assumed here as an example certainly correspond to

those which allow the steam the least practical velocity, for this pressure is never employed, especially in non-condensing engines, and still less in engines whose pistons attain the velocity of 3 mètres a second, a speed that is hardly to be met with in locomotives. Consequently, the proportion $\frac{1}{114}$ may be retained for the purpose of comparing it with that taught by practice.

Instead of short pipes and perfectly regular sections, we have, on the contrary, pipes sometimes very long, furnished with cocks capable of narrowing their section; the slide-valve, instead of uncovering the steam-ports at once, uncover them progressively, and in certain cases incompletely, the pipes are often crooked and the whole of the passages are liable to be cooled by exposure, and so on.

It is easy to see in what proportions these causes of irregularity influence the velocity of the steam, and that it would be impossible to limit the passage to the proportions supposed above.

On account of these numerous effects, more easily described than calculated, constructors have increased the section of the steam-pipe and of the steam-ports; these latter, however, depend in some degree upon the system employed. But the section of these various passages is limited, for the larger the pipes, the more considerable are the lost spaces, and the volumes of circulating steam exposed in proportion to their magnitude to the cooling influence of the atmosphere.

These observations do not apply to the eduction-pipes which may have throughout their length as large a section as possible, if a portion does not serve alternately for the ingress and egress of the steam. This is one of the reasons which have led builders to adopt special eduction-pipes.

It is of special importance to give a sufficient diameter to the eduction-pipe of a non-condensing engine, especially when this pipe ascends to a great height; for the velocity of a gas will be greatly retarded when the ratio between the diameter and the length is very considerable, and this occasions a resisting pressure at the beginning of the passage. It is certain that a fault of this kind may completely derange the performance of an engine, in other respects in perfect order. To avoid this error, especially in the case of small engines, it will be necessary to calculate specially the ratio to be established between the diameter and the length of the outer eduction-pipe, so as to reduce this *counter-pressure* to a degree that is not hurtful.

To reduce to figures the foregoing facts upon which we have been reasoning, we have drawn up the following Table, indicating the proportions adopted in several kinds of engines, by builders, for the induction and eduction pipes and orifices. These engines are characterized in the present Table by their nominal horse-power, the initial pressure of the steam, the degree of expansion, and the diameter and surface of the piston. Several have two cylinders; but the dimensions given refer invariably to one only.

Examination of the succeeding Table.—The first thing that strikes the attention on examining this Table is the want of agreement among the results found, even if we separate each kind of engine, which shows that all builders are not agreed as to the proportions to be adopted between the surface of the piston and that of the steam ports and pipes; or that a certain degree of variation is possible without injuriously affecting the working of engines; for all those given in the Table are of recent construction, and work satisfactorily.

Another remarkable fact is that M. Fargot's engines have the smallest passages, and these engines are known to be very carefully constructed, and to reach the highest degree of utilization of fuel. But it must be remembered that they are regulated for a very considerable degree of expansion.

If, however, we examine this series of fixed engines, the mean speed of the pistons of which is about 1 mètre a second, which engines are all expansive and of a pressure varying from 2·5 to 5 atmospheres, we shall see generally;—

1. The section of the steam-pipe varies between $\frac{1}{35}$ and $\frac{1}{30}$ of the superficies of the piston, without the variation being justified by the special conditions of the engine.

2. The section of the steam-ports, which might be greater than that of the steam-pipe, through which the flow is continuous, exceeds it only by a very little.

3. The exhaust-pipe, between the exhaust-port, the cylinder and the condenser, or the atmosphere, is of a larger section, varying from $\frac{1}{30}$ to $\frac{1}{15}$ of the superficies of the piston, the largest section $\frac{1}{14}$ corresponding to the escape into the atmosphere.

4. The section of the exhaust-port is equal to that of the pipe; nothing hinders it, however, from possessing very large proportions, except the increase in the surface of the slide-valve.

Passing on to the locomotives, the pistons of which move at a speed nearly three times that of fixed engine pistons, we notice a considerable increase of the sections of the steam passages, and particularly those of the ports; the exhaust-pipe, which is also very large at the beginning, is, on account of its particular functions, diminished in a variable manner at the opposite end, which prevents us from giving it a value proportional to that of the piston. And in locomotives, the steam-ports would be $\frac{1}{12}$ and the exhaust-port $\frac{1}{8}$ of the superficies of the piston.

In marine engines we remark the same proportions as in fixed engines, though the conditions of pressure, expansion, and speed of the piston are slightly different. There is, however, an enlargement of the steam passages, and particularly of the exhaust ports and pipes, the section of which reaches $\frac{1}{11}$ and sometimes $\frac{1}{10}$ of that of the piston.

The Table contains one example of a road engine of small power, but great speed, the various parts of which engines are usually of small dimensions. The sections of the pipes and ports are the same as in the fixed engines, and the speed of the piston is not greater. It might have been supposed, however, on account of the frequent pulsations of the mechanism, that this was precisely the case in which a large section should be given to these passages; but the loss of steam would have been greater, and the builder deemed it expedient not to increase the dimensions.

The preceding facts demonstrate that much is gained by providing separate channels for the ingress and the egress, and by suppressing those situated between the slide-valve and the interior of the cylinder; this will allow us to give a larger section to the various orifices. It is useless to

DIMENSIONS OF THE STEAM-PORTS.

INDUCTION AND EDUCTION PIPES BELONGING TO ENGINES OF DIFFERENT SYSTEMS.

KIND OF ENGINE.	Conditions of Motion.			Cylinder		Steam-Pipe.			Eduction-Pipe.			Induction Orifices.		Eduction Orifices.	
	Pressure of the Steam.	Mean speed of the Piston.	Ratio of the introduction to the Stroke.	Diameter.	Section.	Diameter.	Section.	Ratio of this Section to that of the Cylinder.	Diameter.	Section.	Ratio of this Section to that of the Cylinder.	Section.	Ratio of this Section to that of the Cylinder.	Section.	Ratio of this Section to that of the Cylinder.
	atmospheres.	mètres.		millimètres.	sq. centimètres.	millimètres.	sq. centimètres.		millimètres.	sq. centimètres.		sq. centimètres.		sq. centimètres.	
FIXED ENGINES.															
Bourdon, horizontal, 25-h., condenser	3·5	1·16	$\frac{1}{5}$	420	1385	80	50	$\frac{1}{27·7}$	100	78·5	$\frac{1}{17·6}$	44·4	$\frac{1}{31}$	51·8	$\frac{1}{26·7}$
Bréval " 20-h. "	4	1·50	$\frac{1}{5}$	350	962	60	23·3	$\frac{1}{41}$	100	78·5	$\frac{1}{12·2}$	43	$\frac{1}{23·8}$	71·5	$\frac{1}{13·4}$
Fargot " 60-h. "	5	1·56	$\frac{1}{15}$	650	3318	80	50·3[b]	$\frac{1}{66}$	120	113	$\frac{1}{29}$	85	$\frac{1}{39}$	·119	$\frac{1}{30}$
" " 20-h. "	5	1·28	$\frac{1}{15}$	415	1353	62	30	$\frac{1}{45}$	100	78·5	$\frac{1}{17}$	33	$\frac{1}{41}$	38·5	$\frac{1}{36}$
Powell, 2-cylinder, Woolf, 70-h., condenser	2·5	1·10[a]	$\frac{4}{5}$[b]	500[c]	1963	100	78·5	$\frac{1}{25}$	140[d]	154	$\frac{1}{12·7}$	123·5[e]	$\frac{1}{16}$	174·2[f]	$\frac{1}{11·2}$
Schneider, single-stroke, 170-h. " ..	3·5	1·00	..	1m·800	25447	300	707	$\frac{1}{36}$	390	1195	$\frac{1}{21·3}$	880	$\frac{1}{29}$	..[g]	..
Cail and Co., horizontal, 8-h., non-condenser	5	1·24	$\frac{1}{6}$	320	804	65	33·2	$\frac{1}{24·2}$	85	57	$\frac{1}{14}$	31	$\frac{1}{26}$	54	$\frac{1}{14·9}$
LOCOMOTIVES.															
Buddicon, tender engine	8	3·36	..	420	1385	100	78·5	$\frac{1}{17·6}$	Elliptic	203	$\frac{1}{6·8}$	118	$\frac{1}{11·7}$	253·7	$\frac{1}{5·4}$
Cail, Crampton's system	..	3·50	..	400	1257	120	113	$\frac{1}{11·1}$	160	201	$\frac{1}{6·2}$	106·4	$\frac{1}{11·8}$	228	$\frac{1}{5·5}$
MARINE ENGINES.															
Mazeline and Co., yacht l'Aigle	2·5	1·58	$\frac{3}{5}$	1m·800	25447	360	1018	$\frac{1}{25}$	460	1662	$\frac{1}{15·3}$	1320	$\frac{1}{19·3}$	2244	$\frac{1}{11·3}$
" screw, 1000-h.	2·5	2·16	$\frac{1}{8}$	2m·100	34636	..	1608	$\frac{1}{21·5}$	630	3117	$\frac{1}{11·1}$	1200[f]	$\frac{1}{29}$	2300	$\frac{1}{15}$
Nillus, screw, 30-h...	2·5	1·28	$\frac{1}{8}$	500	1963	120	113	$\frac{1}{17·4}$	160	201	$\frac{1}{9·7}$	77[f]	$\frac{1}{25·5}$	198	$\frac{1}{10}$
Flaud, road engine, 5-h...	6	1·25	$\frac{3}{4}$	140	154	30	7·1	$\frac{1}{21·7}$	35	9·6	$\frac{1}{16}$	6	$\frac{1}{25·7}$	9	$\frac{1}{17}$

[a] Of the small piston. [b] In the small cylinder. [c] Diameter of the small cylinder. [d] Escape from the small to the large cylinder.
[e] Small cylinder. [f] Effective opening. [g] The same as for the introduction.

increase the size of the exhaust-port; the steam. to reach it, must traverse the same channel of reduced section by which it entered.

Lineal Dimensions of the Ports.—The steam-ports being rectangular, the proportions of their sides may have different values, among which we have to seek the most advantageous.

From the point of view of the quickest opening, that is, of the largest passage offered at the beginning of the stroke of the slide-valve, supposing the same method of working the valve, the ratio between the height and the breadth of the orifice will be of no consequence, for each fraction of the surface uncovered being, like the whole surface, proportional to the stroke of the valve, it follows that, whatever this ratio of the two dimensions may be, a given fraction of the stroke always corresponds to the same fraction of the surface uncovered. But if we consider all the functions of the slide-valve, we shall see at once that, on the contrary, there are weighty reasons for making the orifices *broader than high*, that is, in the form of a narrow rectangle, *having its short sides in the direction of the stroke of the valve.* Indeed, the total surface of the valve is, in every case, proportional to that of the orifices, or, to be more exact, will have the same external surface, whatever the ratio of their sides may be; consequently it will be subject to the same pressure. Now the work which its friction absorbs being the product of this pressure by the space passed over, to reduce this resistance to its minimum we must evidently diminish this space as much as possible; that is, *lengthen* the orifices, and place the short sides *in the direction of the stroke of the valve.* If the valve be worked by means of a circular eccentric, we have another reason for reducing the stroke as much as possible; for the general dimensions of the circular eccentric increase in very great proportions with the stroke which it has to produce.

This being the general rule, the ratio to be adopted is not absolute. Thus, it is necessary, in the case of a *short* cylinder, to lengthen considerably the orifices in order to reduce the length of the steam-chest; with a cylinder of ordinary proportions the same reason does not exist, but the question of the eccentric remains. For examples, we call attention to Fargot's engine of 60 horse-power, which has a long stroke, and to Mazeline's engine of 1000 horse-power, which, on the contrary, has a relatively short stroke.

In the engine of 60 horse-power, the induction-ports are 5 centimètres by 17, which corresponds to the ratio $\frac{1}{3\cdot4}$. In the marine engine of 1000 horse-power, the whole breadth of these orifices is 125 millimètres, 80 millimètres of which are uncovered by the valve for the introduction, and the whole breadth for the egress; the length is equal to $1^{m}\cdot500$, in two parts of $0\cdot750$ each. Taking as a basis the quantity uncovered, the ratio of the sides of these orifices would be 8 to $150 = \frac{1}{18\cdot75}$.

These two examples are intended to give an idea of what may be found in practice, but they will lead to no rule. Each particular case will require different proportions which cannot possibly be foreseen. In engines of two cylinders it is desirable to give the same length of stroke to each of the two slide-valves, in order that they may be worked by the same eccentric, or the same contrivance, and to this end the orifices of the two cylinders being of different sections and requiring to possess an equal height, those of the smaller cylinder are made nearly square.

It seems to us unnecessary to dwell longer on a subject which rests upon such unfixed bases, especially as we believe the preceding Table, which shows the proportions adopted by experienced builders, to be a sufficient guide in practice.

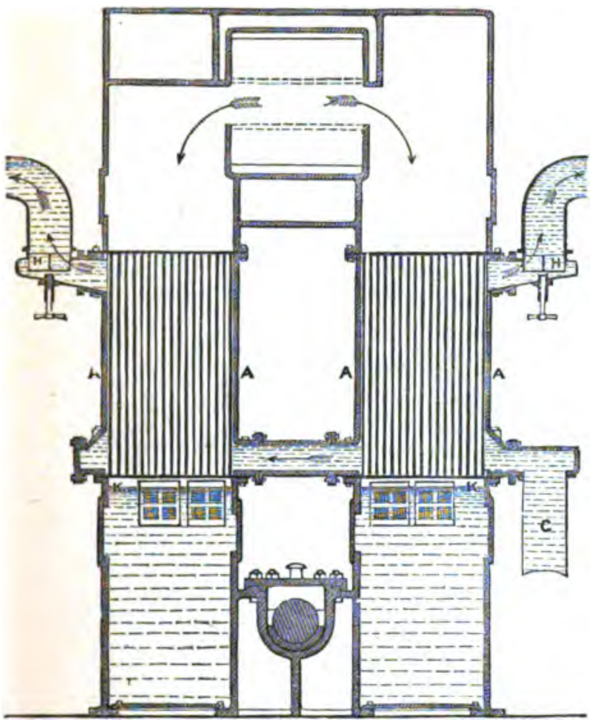
Figs. 2297, 2298, are of the condensers of the Mooltan and other vessels: these condensers were constructed under the superintendence of Edward Humphrys, after the designs of that ingenious and well-known inventor Samuel Hall, of Basford. The Peninsular and Oriental Company's ships Mysore and Rangoon, of 400 nominal horse-power, were furnished with condensers by Humphrys like those exhibited in Figs. 2297, 2298. The boilers of each of the last-named ships contained 4800 square feet of heating surface, and the condensers of the Mysore and Rangoon contained 4712 square feet of condensing surface, and those of the Mooltan 4200 square feet. The indicated power of the Mooltan when tried officially was 1734 horse-power; hence the area of condensing surface for each indicated horse-power was rather less than $2\frac{1}{2}$ square feet.

For convenience of manufacture and arrangement of these engines, the condenser of each is divided into two parts A A, Fig. 2297, each part being exhausted by its own air-pump B, Fig. 2298, so that each pair of engines is provided with four air-pumps and four condensers. The air-pump B is 18 inches diameter with a stroke of 3 feet. These dimensions being used by Humphrys with injection condensers in engines of the same nominal power, he believes they are larger than necessary for surface condensers of engines in good condition, with condensing water at the average temperature of the sea in this climate; but as these engines had to be employed in the Indian seas, it was considered expedient to provide large air-pumps and large pumps for circulating the condensing water, so as to allow of almost any quantity of condensing water being driven through the condensers that may be found necessary in an Indian climate. The air-pumps B discharge their water direct into the boilers through the pipe C, according to Hall's plan, so that no feed-pumps are necessary. The air which leaks into the engines is allowed to escape by an open stand-pipe connected to the highest point of the feed-pipe, and carried up inside the mast, which is of iron, to a greater height than is due to the pressure of steam in the boilers. A valve regulated by a float was originally fitted to the Mooltan for allowing the escape of the air; but it was found to require some little attention, and hence the stand-pipe was substituted which answered perfectly without much attention.

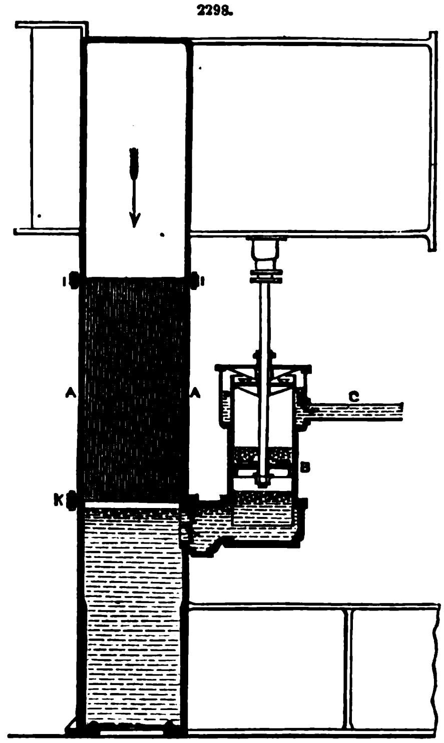
Each condenser A A, Figs. 2297, 2298, contains 1178 seamless drawn pure copper tubes, $\frac{3}{4}$ in. outside diameter and No. 18 wire-gauge or $\cdot050$ in. thick, 5 ft. 10 in. long, weighing 28 oz. each tube, and fixed at 1 in. pitch centre to centre, as shown in Figs. 2299, 2300. The tube-plates of the Mooltan are of cast gun-metal $\frac{7}{8}$ in. thick; but those of the Mysore and Rangoon are of rolled copper, finished $\frac{5}{8}$ in. thick. These are first set as flat as possible, and the tube-holes marked out

upon them. The holes are then drilled under a common drilling machine with a drill of two diameters, shown in Figs. 2301, 2302, having a guard D upon it to fix the depth to which the larger diameter shall penetrate the plate. One machine, worked by an ordinary driller, drilled the 1178 holes in the tube-plate in seventy hours. The tapping of the holes is then proceeded with,

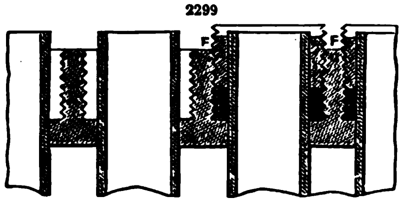
2297.



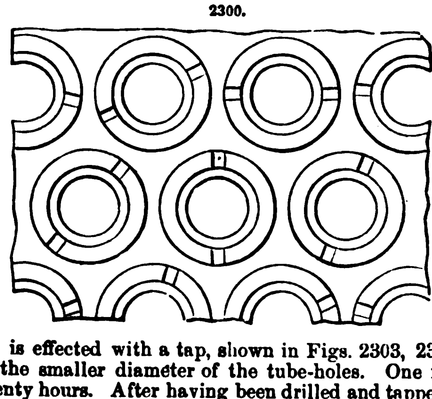
2298.



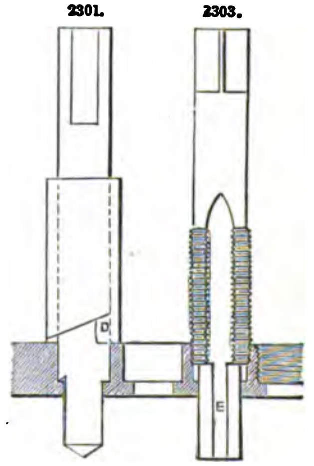
2299



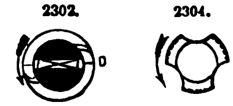
2300.



2301. 2303.



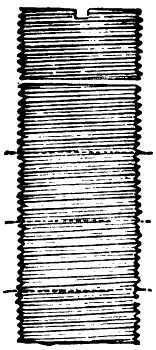
2302. 2304.



and is effected with a tap, shown in Figs. 2303, 2304, having a parallel end E to guide it, which fits the smaller diameter of the tube-holes. One man of ordinary skill tapped the 1178 holes in seventy hours. After having been drilled and tapped, the tube-plate is again set perfectly flat on a surface-plate, and then both sides are faced off in a lathe or planing machine.

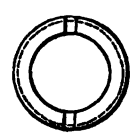
The screwed glands F.F, Fig. 2299, for securing the packing at the ends of the tubes, are made from Muntz' metal solid-rolled tubes, which are obtained in lengths of about 5 ft., rolled to gauge both inside and outside; the inside diameter is exactly that of the outside of the copper tubes, namely $\frac{5}{8}$ in., and the outside diameter is such that when screwed it will exactly fit the tapped holes in the tube-plates. It is screwed on the outside as it comes from the maker in a common screwing machine, as shown in Figs. 2305, 2306, and is then cut by a circular saw into $\frac{1}{2}$-in. lengths to form the glands. The saw marks are taken off the ends by a facing cutter revolving in a lathe, shown in Figs. 2307, 2308, and the same operation clears out the inside of the hole. The notch for the screw-driver is cut by passing a number of the glands, when screwed into a plate, under a revolving circular saw of the required thickness. The packing is composed of linen tape; a piece of this tape, 12 in. long and $\frac{7}{16}$ in. wide, is wound round a mandrel, the ends and edges being slightly stitched, in which state it is readily put into the tapped holes of the tube-plate, and when screwed down by the gland forms a very perfect and lasting joint. The thickness of the tape is such that 1000 of these packings weigh about 2 lbs.

2305.

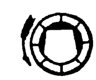


2307.

2306.



2308.



The exhaust steam from the engines passes down through the interior of the condenser tubes, and the sea-water for keeping the tubes cold is driven up through the spaces between the tubes. The sea-water is admitted through an inlet-pipe fitted with a slide-valve at the bottom of the ship, and enters the condensers at the bottom by the pipe G, Fig. 2297; it then circulates round the outsides of the tubes, and makes its exit through the regulating valves H H at the top of the condensers, at about the load water-line of the vessel. The valves H H answer the purpose of regulating the flow of sea-water equally through the two divisions A A of the condenser, and also of shutting out the water from above when the outsides of the condenser tubes have to be examined. The flow of water is produced by one of Appold's centrifugal pumps, the diameter of the revolving disc being 36 in.; it is driven by a pair of wood and iron spur wheels, the proportions of which are about 1 to $3\frac{1}{2}$, so that at the ordinary speed of the engines of the Mooltan, namely, 56 revolutions, the pump made 194 revolutions a minute. Two of these pumps were provided, the second being driven by an auxiliary engine to be used in case of the failure of the other.

The condensers of the Mooltan, in 1862, had run 42,000 miles; and at the end of 30,000 miles the engineer examined the inside and outside of the condenser tubes, and found the outsides perfectly clean; but inside there appeared a slight coating of grease resulting from the lubricating material employed in the interior of the engines. This was, however, so slight as not to affect the action of the condensers; the vessel ran the last 300 miles of the 30,000 at an average speed of 60 revolutions a minute with 24 lbs. steam in the boilers, and the vacuum in the condensers supporting a column of mercury $27\frac{1}{2}$ in. high. A very careful examination of the inside of the boilers showed that the action of the surface condensers, returning always pure water into them, is likely to ensure their continued efficiency, as there was no appearance of deterioration whatever. The lubricating material employed in the engines collects in the boilers, adhering to the sides and stays about the water-line, and is to be found in large lumps in the bottom water-space below the furnaces; this requires to be taken out occasionally, otherwise, in the opinion of the engineer in charge, it causes the boilers to prime.

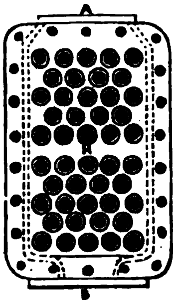
Before determining on adopting exactly Hall's mode of manufacture for the condensers, although his experience of it had been very favourable, Humphrys examined the other plans for surface condensation, in most of which the joints between the tubes and tube-plates are made with vulcanized india-rubber; but having understood that a chemical action took place between the copper of the tubes and the sulphur employed in preparing the india-rubber, and not being able to discover in the new plans any advantage over Hall's condenser, he adhered to this construction in the condensers of the Mooltan. As regards the action of the vulcanized india-rubber on the copper tubes, the writer placed a piece of copper tube inside a piece of vulcanized india-rubber tube, and carefully washed and weighed the copper tube every month, and found a gradual decrease in its weight.

In designing the engines of the Mooltan no provision was made for cleaning either the insides or the outsides of the tubes of the condensers, except that the connection between the condensers and cylinders was so arranged as to admit of the ready removal of the entire condenser case with its tubes. Each condenser case is a rectangular vessel about 2 ft. 10 in. by 3 ft. 6 in., and 5 ft. 10 in. high, as shown in Figs. 2297, 2298; and by removing the bolts in the joints I and K at top and bottom, the entire condenser with its tubes can be drawn out clear of the cylinder, and the inside of the tubes can then be cleaned, the tube-plates being in this case of gun-metal cast with the edge thickened $\frac{1}{2}$ in. all round on the outer face, so as to clear the projecting glands of the tube ends. The two condensers of one engine might be removed, the tubes cleaned, and the condensers refixed in forty hours; but up to 1862 there was nothing in the state of the condensers to indicate the necessity of cleaning either the insides or outsides of the tubes; indeed the outsides were cleaner and brighter than when the tubes were first fixed in their place. When it becomes necessary to clean the insides, it is recommended to apply a solution of caustic soda by filling the condenser with it up to the top of the upper joint I; this was also the practice followed by Hall with success in his condensers in 1837. Indeed Hall's condensers were employed in the Penelope for more than six

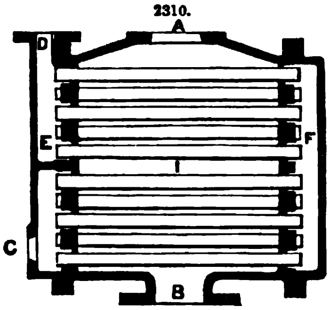
years, and the engineer in charge during that period stated that, with the exception of occasionally cleaning out the insides of the tubes by the application of a solution of soda and water, the condensers never gave an hour's trouble.

The illustrations, Figs. 2309 to 2311, are of David Marshall's plan for packing surface condensers. The tube packing of Marshall is simple, effective, and reliable, it requires neither screws nor glands to effect the required tightness.

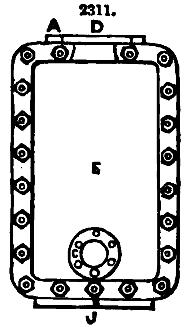
2309.



2310.



2311.

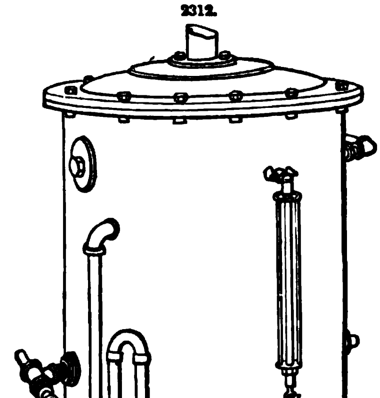


References:—A, Exhaust steam inlet from engine cylinders. B, Outlet to air-pump of engine. C, Inlet for circulating water. D, Outlet for circulating water. E, F, Portable covers or doors. G, The tube packing. The circulating water in centre of packing presses outer ring to tube-plate and inner to tube, thereby making a perfect tight joint, and still allowing tube to expand. H, Front view with door off, showing tubes and packings. I, Longitudinal section, showing tubes, packings, and doors. J, Front view with door on, showing inlet and outlet C, D.

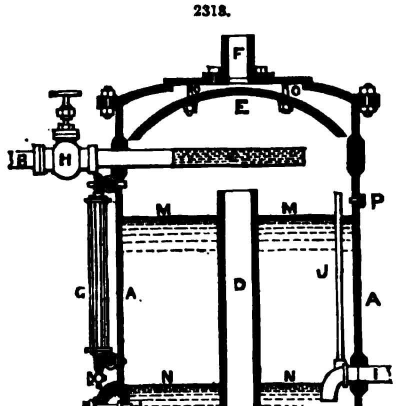
The efficiency of this packing has been carefully tested on board many ships. Andrew Brown, one of Simon and Co.'s engineers, states that when one of their ships, the Africa, was running with 60 lbs. pressure, the vacuum was steady at 27½ in. of mercury, and that all the joints made by this packing were perfectly tight.

Fig. 2312 is an elevation, and Fig. 2313 is a section, of a simple form of feed-water heater, invented by H. N. Waters, and intended to be used with non-condensing engines. Referring to the section, Fig. 2313, it will be seen that the heater consists of a reservoir or casing A, into which the cold water flows from a cistern through the pipe B and perforated pipe or sprinkler C, this latter distributing it in the form of a number of fine jets. The flow of water is regulated by the cock H, so that it is maintained at a proper level in the casing, as shown by the glass gauge G.

2312.



2313.



The exhaust steam from the engine enters through the pipe D, and impinges against the deflector E, which deflects it downwards again against the sprinkler C. That portion of the steam which is not condensed passes round the edges of the deflector E to the exit-pipe F at the top of the apparatus. The feed-pipe I, leading to the pump, is turned down inside the reservoir, and terminates about 4 in. above the bottom of the casing, so that the pumps can draw without disturbing the sediment. At the bend of the pipe I there is attached an air-pipe J, which extends upwards above the highest water-level M in the reservoir. This pipe is for the purpose of admitting air or steam to the pumps through the pipe I when the water-level falls below the line N, so that the pumps cannot draw off the water below that level. When the pump is situated below the

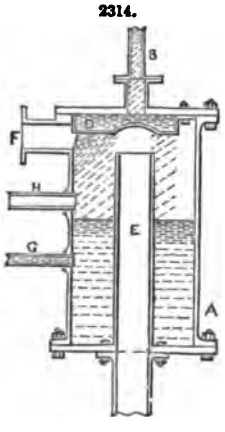
pipe I, the water will flow out to the level N of the bottom of the inside of the pipe; but when the pump is above I, the lowest water-level producible will be on a line with the top of the inside of the pipe I. At L is a hand-hole for giving access to the interior of the heater for cleaning or other purposes; while K is a plug for drawing off the water from the casing when desired, and P is an overflow-pipe, or plug, to prevent the water from rising sufficiently high to enter the pipe D.

In addition to acting as a water-heater merely, the arrangement we have described serves to collect the major portion of the solid matters contained in the feed-water, and thus greatly diminishes, and in many instances entirely prevents, the formation of scale in the boilers. By the employment of the sprinkler the water is brought into such intimate contact with the exhaust steam that it is raised quite to the boiling-point, and the arrangement of the reservoir and feed-pipe allows the solid matters which become separated at that temperature to be deposited before the water is pumped into the boiler.

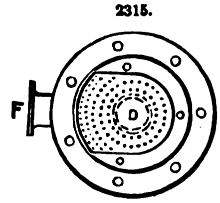
Fig. 2314 is a section, and Fig. 2315 a plan, of heater with cover removed, showing the form of a rose. This arrangement was invented by Thomas Aimers. The heater consists of a cylinder A, into which the cold water is introduced by pipe B, having a regulating cock C to maintain water at a proper level in the cylinder. On the under-side of the cover of the cylinder there is a rose D, into which the water flows from the pipe B; this rose is bored full of small holes, as shown in Fig. 2315, but the part immediately over the exhaust-pipe E has no holes in it, so that the water falls around the pipe in a continuous shower, and thus any water is prevented from entering the exhaust-pipe and becoming a drag upon the engine. The exhaust steam from the engine enters through the pipe E and impinges against the curved part of the rose; this throws it out upon the shower of water, through which it must necessarily pass before it makes its escape through the exit-pipe F, and the holes in the rose being more numerous over the entrance to that pipe, the full benefit is got from the steam. The feed-pipe G leading to the pump is placed at a considerable distance from bottom of cylinder, so that the pump can draw without disturbing the sediment. H is an overflow-pipe to prevent the water rising sufficiently high to enter pipe E.

This arrangement always gives an abundant supply of water almost at the boiling-point, by turning the cock C full on, and allowing the extra water to run through the overflow into a cistern. For a factory where hot water is much used this is a great advantage. The condensation of the steam is complete, and effectually takes off all back pressure from the engine.

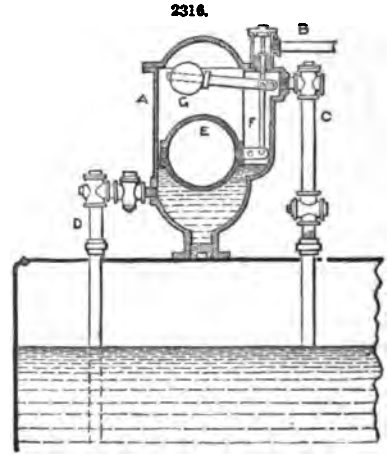
2314.



2315.



2316.



The Siphon Feed-water Regulator and Purifier, Fig. 2316.—The objects intended to be accomplished by this contrivance are fourfold; the regulation of the water fed to a steam-boiler; the absolute prevention of low water; the prevention of explosions, or injury to boilers so frequently caused by unequal expansion and contraction from the variable temperature at which water is usually fed to the boiler; and the purification of the feed-water before reaching the boiler, and the deposition and easy removal of the deposit. The apparatus is very simple in construction and entirely automatic in operation. It is, in reality, a siphon, the short leg of which is alternately a conduit for water and steam. Fig. 2316 is a section showing its internal construction. The reservoir or dome A is of cast iron, in the form shown, bolted to the top of the boiler at the point deemed most convenient. At its top it receives a pipe B connected with the feed-water pump and is the water supply pipe. The passage from the interior end of this pipe to the dome A is governed by an ordinary upward-lifting valve, or check-valve. Just below the inlet-pipe B is the pipe C, connecting with the steam-space of the boiler, having its lower end at the desired level of the water and forming the short leg of the siphon. Near the bottom of the dome is another pipe D, forming a communication with the dome and the water-space of the boiler, its lower end reaching nearly to the boiler bottom. This is the long leg of the siphon. Both these pipes are open at the bottom, and each is provided with cocks to be used, if necessary, to close communication between the interior of the dome and the boiler when the dome is to be cleared of the sediment deposited by the water. Inside the dome is a hollow lever float E pivoted to the rod F and balanced by the adjustable weight G.

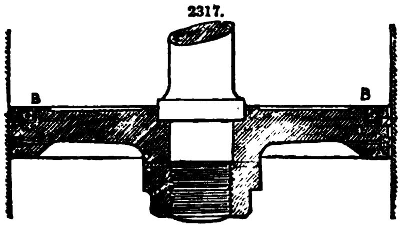
When the water falls below its proper level, exposing the open lower end of the pipe C, steam, of course, passes up into the dome A, and the water contained in it and supporting the float E will descend, carrying with it the float and opening the valve to the inlet of water through the pipe B.

So long as this valve is open, water will consequently be forced in by the pump through the pipe D to near the bottom of the boiler. Soon as the water rises sufficiently to cover the end of the pipe C, no more steam will enter the dome, equilibrium will be restored, and the valve closed. If the pump is kept continually at work a side pipe may be used to carry off the overplus of water. Thus the height of water in the boiler will be automatically preserved at an absolutely uniform level.

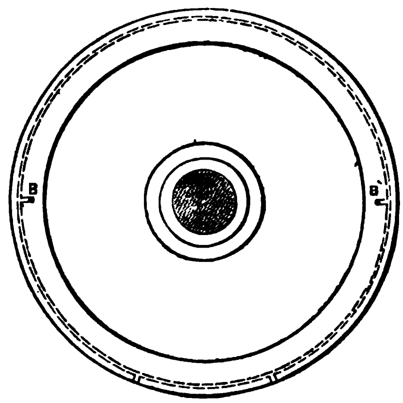
The apparatus heats the feed-water in the chamber A to the same temperature as the water in the boiler, thus preventing the unequal expansion and contraction of the iron. In addition to this office of the apparatus, it is intended also to separate and precipitate the salts and earthy matters held in solution, as the water admitted to the dome becomes vaporized by the steam admitted through the pipe C, and consequently parts with its impurities, which, being specifically heavier, sink to the bottom of the dome, from which they can be readily removed on taking off the top of the dome. Applied to marine or other boilers subject to foaming, the apparatus will work as a regulator to the feed, as well as where there is no such annoyance.

Packing for Pistons.—This packing, introduced by G. M. Miller, consists of two rings, pressed outwards against the cylinder by the pressure of the steam as it acts on the alternate faces of the piston, without the use of any springs. The construction of the piston is shown in Figs. 2317 to 2319, as used by Miller in the locomotive engines on the Great Southern and Western Railway of

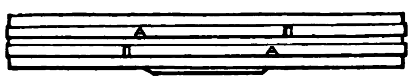
2317.



2318.



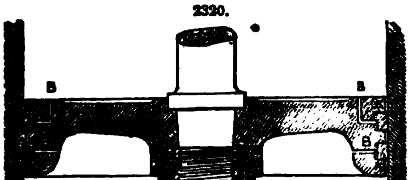
2319.



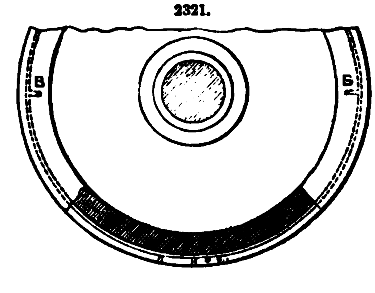
Ireland. The piston is of cast iron, 2 in. in thickness and 15 in. diameter. Two square grooves A A are turned in the edge of the piston, $\frac{3}{8}$ in. in width and $\frac{3}{8}$ in. apart, and a corresponding steel ring is fitted into each groove, the rings being divided at one part with a plain butt-joint, and sprung over the piston into their places. Two small holes B B, $\frac{1}{8}$ in. diameter, open from each face of the piston to the bottom of the nearest groove, whereby the steam is admitted behind the packing ring and presses it out against the cylinder so long as the steam is acting upon that face of the piston. The alternate action of the two rings is continued as long as the steam is acting on the piston, one of them being always pressed steam-tight against the cylinder.

In Figs. 2320 to 2322, is shown one of the pistons with brass rings which are $\frac{3}{8}$ in. width and $\frac{1}{16}$ in. thickness, the piston being $3\frac{1}{4}$ in. wide.

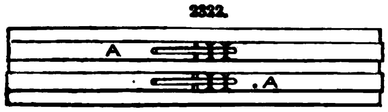
2320.



2321.



2322.

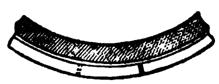


Another form of the piston has been used in cases where the piston is desired to be flush on both faces or to fit a cylinder with flat covers; in this a circular flat head forged upon the piston-rod is fitted between the turned faces of the two halves of a cast-iron piston, which are held together by turned pins riveted over, forming a hollow piston flush on both faces, fast upon the piston-rod, and without any loose part besides the two packing rings.

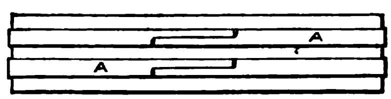
The ends of the rings where divided are made with a butt-joint, as in Fig. 2319; or with a lapped joint, as shown in Figs. 2323, 2324. The piston body is turned to pass through the cylinder easily; and the joints of the rings have been found to be practically steam-tight. In some cases

the joints have been tongued, as shown in Fig. 2322, but in Miller's experience this has not been found requisite; the butt-joint has invariably worked well, whilst it has the advantage of perfect simplicity of construction. In pistons where the packing ring travels over the opening of the cylinder port a small stop is fixed in the bottom of the groove, entering a short slot in the packing ring, to prevent the ends of the ring coming opposite the cylinder port, but still leaving the ring free to travel round a little in the piston grooves; but it is preferred for the packing rings not to travel over the cylinder ports.

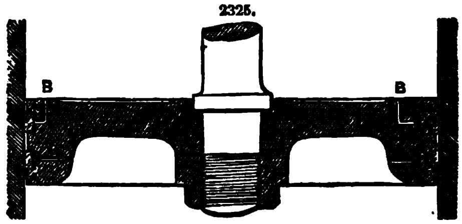
2323.



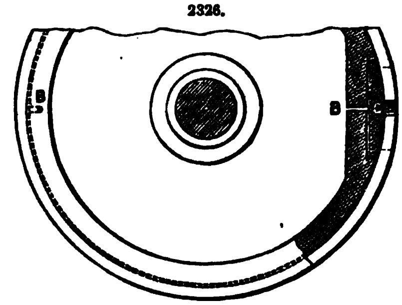
2324.



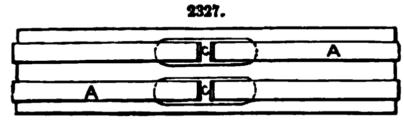
2325.



2326.



2327.



Another form of joint for the packing rings is shown in Figs. 2325 to 2327, intended to be used in a stationary engine with cylinder 16 in. diameter. A brass stop-piece C, 1 in. thick and 4 in. long, is placed in a recess at the back of the joint, serving as a cover to the joint at the top and bottom by projecting ⅛ in. in thickness on each side of the ring.

These steam-packed pistons have been used more than seven years in the locomotives of the Great Southern and Western Railway, and have proved so satisfactory and advantageous that their use has been extended to all the locomotives working upon that line. The following are the results of the working in the engines running from Dublin, as regards the durability of one set of rings, the period of their wear, and the mileage of the engines whilst wearing them out. Nineteen engines working with one set of steel rings averaged 33,020 miles and 16½ months' running, one engine having worked for three years and run as much as 98,073 miles with one set of packing rings. Five engines working with one set of brass rings under the same circumstances averaged 30,986 miles and nineteen months' running, the greatest work amongst them being 2¼ years and 42,197 miles. Twenty other engines with steel rings which were in use in 1862 also averaged 40,444 miles and twenty-one months' work, one of these having worked for 3¼ years and run 94,399 miles with the original set of rings.

The general result of the above is that one set of steel packing rings have lasted 37,000 miles and nineteen months' work, and one set of brass rings 31,000 miles and nineteen months' work, the difference in durability being about 16 per cent. in favour of the steel rings. In some of the individual cases of the pistons with steel rings, a very considerable variation from the average result of 37,000 miles is found in the durability of the packing rings, some of them having lasted 2¾ times the average and some only as much below the average. In the case of the brass rings the variation is not so great, amounting to 1¾ times the average in the highest and about as much below the average in the lowest. This variation in wear has not been fully accounted for; it may have occurred from a different character of metal in the cylinders, from priming of the boiler, and from the presence of grit in the water; but the writer has reason to believe that the rings have been frequently put into work and set with a pressure upon the cylinder from their own elasticity, thus causing a source of wear. It is found the best plan to turn the rings to the exact diameter of the cylinder, and to put them in without any spring upon them, so that they are not subjected to any wear except when the steam is acting on them. The steel rings are now slightly tempered, to admit of their being sprung into the grooves without altering their form. In all these pistons the steel packing rings were ⅝ in. thick originally and ⅜ in. wide, and they were worn down to about ⅛ in. thick in the thinnest part before being removed. The brass rings are worn down from $\frac{7}{16}$ in. until they are ⅛ in. thick. It must be remarked that when opportunities occur, as when engines are under repair, the rings are taken out and re-set to the size of the cylinder.

It is found in practice that two steam-ports of ⅛ in. diameter are quite sufficient for each of the steel packing rings, drilled in the position B B shown in Figs. 2317 to 2330. The rings must be made to fit easily in their grooves, so as to move freely, with a clearance of $\frac{1}{16}$ in. at the bottom of the grooves for the steam to pass round behind the rings. No difficulty has been experienced from the steam passages becoming stopped up with a moderate use of tallow in the cylinders.

The use of this piston packing in locomotive engines has been productive of economy by reducing the friction and by prolonging the wear of both pistons and cylinders. It will be observed that only one ring is in action at the same time, and that when the steam is shut off, as in descending inclines and approaching stations, the piston is free to move without any friction. The operation

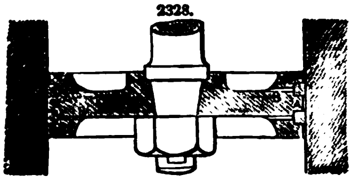
of putting in these rings so as simply to fit the cylinder is extremely easy, whilst great care and skill are required in giving springs the requisite degree of elasticity and in making them maintain it.

A number of stationary engine pistons are working with these packing rings, and they have proved very durable and thoroughly satisfactory, giving an advantage in reduction of friction, and in preserving the cylinder face in perfect condition. In one case of the engine of the Oldbawn Paper Mill near Dublin, with vertical cylinder 18 in. diameter and 2½ ft. stroke, working with 50 lbs. steam, the cylinder had previously been worn considerably out of truth and much grooved, and one of these pistons was put in having two steel rings of ¾ in. width and ⅜ in. thickness, and was in constant work for four years without the packing rings requiring renewal. They have lately been taken out for examination, and were found to be still ¼ in. thick; and the cylinder from its previous defective condition has been brought completely to truth throughout, with a highly polished surface.

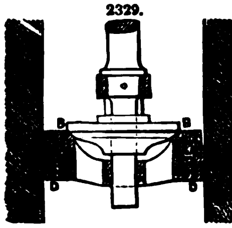
These packing rings have also been used for four years for Pump Buckets, and have proved very satisfactory. In one case of a double-acting pump 8 in. diameter, shown in Fig. 2328, the two packing rings A A are of brass, ¾ in. wide and $\frac{5}{16}$ in. thick, and are pressed out by the pressure of the water acting at the alternate faces of the bucket through two ports B B, ⅛ in. diameter, similar to those in the steam-pistons. This pump had two years' constant work at quarries and bridge foundations upon the Great Southern and Western Railway, before the packing rings required renewal.

In the case of single-acting pumps the bucket has only a single packing ring with ports opening from the upper side, as shown in Fig. 2329, which represents a pump bucket 5 in. diameter that has been working constantly for 2½ years at a station on the railway near Dublin. The packing ring A was originally ½ in. wide and ¼ in. thick, and has worn less than $\frac{1}{16}$ in. in the 2½ years. As the diameter in this case is too small to allow of the ring being sprung over the body of the bucket into its place, it is put in by means of a junk-ring D screwed on at the under-side of the bucket, as shown in Fig. 2329.

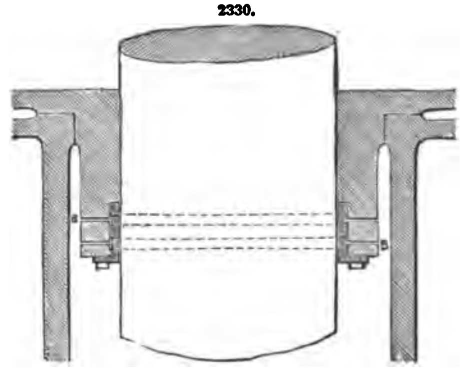
2328.



2329.



2330.



An application of the same construction of packing that has also been made to the gland packing of a 9-in. pump-plunger is shown in Fig. 2330; in which two brass packing rings are used, ½ in. wide and ⅜ in. thick, just like the piston packing rings, except that they act in the opposite direction, being pressed inwards upon the plunger by the pressure of the water through the ports B B.

Naylor's Safety-Valve.—This improvement in the construction of the safety-valves at present in use on locomotive, marine, and stationary engine boilers, for the purpose of preventing the pressure of the steam whilst blowing off through the safety-valve from rising beyond the limit to which the valve is adjusted. This rise of pressure during blowing off is found to take place to a greater or less extent in all steam-boilers with ordinary safety-valves, including locomotive, marine, and stationary boilers; but it occurs especially with locomotive boilers, where the safety-valves are pressed down by levers with spring balances at their extremities, and the rising of the valve in blowing off causes a lifting of the lever and a considerable extra extension of the spring balance and consequent increase of pressure upon the valve.

From experiments made by W. Naylor with locomotive boilers, he believes that a clear available opening of $\frac{1}{10}$ of a sq. in. will allow the steam to escape as fast as it can be generated in a large locomotive boiler at a pressure of 120 lbs. to the sq. in., when the engine is not consuming steam by running, and with the help of a steam-jet in the chimney. Taking the theoretical velocity of steam at that pressure issuing into the atmosphere as 1900 ft. a second, the practical velocity of the issuing steam, allowing for its friction in passing the safety-valve and the resistance of the atmosphere into which it has to flow, may be assumed at 70 per cent. of this amount or 1330 ft. per second. This velocity with the above-named opening of $\frac{1}{10}$ of a sq. in. gives a discharge of 11,172 cub. in. of steam passing off per second. Taking the relative volume of steam to water at that pressure as 203 times, this is equivalent to an evaporation of about 12 gallons of water a minute (11·94); or a consumption of about 8 cwt. (7·99) of coal an hour, taking the evaporative duty at 8 lbs. of water the lb. of coal.

The present large locomotive boilers are made some with two safety-valves of 3½ in. diameter,

some with two valves of 4 in. diameter, some with two of 5 in. diameter, and some engines are working with four valves of 3 in. diameter; the valves being loaded by spring balances through levers, or in some cases by a spring acting direct, without the intervention of a lever. When the spring balance and lever are used, the proportions of the lever are generally arranged so that 1 lb. pressure of the balance is equal to 1 lb. the sq. in. on the valve; and then the perpendicular lift of the valve in opening multiplied by the number of square inches in its area gives the distance that the outer end of the lever has to move to allow the required opening of the valve; and this lift of the lever end multiplied by the number of lbs. to the inch in the graduations of the spring balance gives the number of lbs. the square inch of additional load put upon the valve by the act of lifting, and the corresponding increase of pressure necessitated in the steam to admit of its escape through the opening of the valve, in addition to that required for overcoming the friction of the steam in passing the valve and the resistance to it in flowing into the atmosphere.

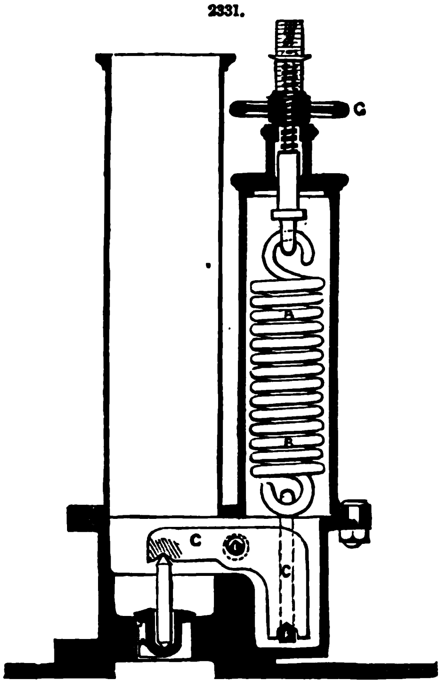
Taking the case of two valves of 5 in. diameter, giving a combined circumference of 31·4 in., and say 30 lbs. to the inch as the graduation of the spring balances, with a ratio of leverage (or area of valve) of 19·63 to 1, a total area of discharge of $\frac{7}{10}$ sq. in. would require a lift of the valves of $\frac{0\cdot7}{31\cdot4}$ or ·0223 in.; but as the bearing faces of the valve and seat are not horizontal but inclined at 45°, a vertical lift of the valve equivalent to 1 sq. in. (0·99) annular area is required for giving a discharging area of $\frac{7}{10}$ sq. in.; and the total lift will therefore be ·032 in. This gives an extension of the spring balance of ·032 × 19·63 or ·628 in., causing an extra load upon the valve of ·628 × 30 or 18·8 lbs. a sq. in. in order to get the required opening for discharge of the steam. The result is therefore that, in order to give a sufficient area of opening for the discharge of all the steam that the boiler is capable of generating, the pressure must rise in the boiler about 19 lbs. to the sq. in. above the intended limit of the working pressure, or the point at which the safety-valves are adjusted to begin blowing off; and this action of increasing the total pressure upon the valve as the valve rises is inseparable from all arrangements in which the valve is pressed down by a spring acting either through a constant lever or direct upon the valve.

Naylor's safety-valve has been designed to remove this defect, by causing the spring that presses upon the valve to act not through a constant lever, but through one which varies in its effective length, diminishing in length as the valve rises in the same proportion that the tension of the spring is increased by the rising of the valve, so as to prevent any increase taking place in the total pressure upon the valve.

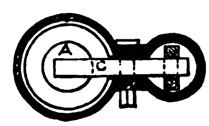
Naylor's valve is shown in Figs. 2331 to 2334, Fig. 2331 being a vertical section, and Fig. 2332 a sectional plan.

The safety-valve A is only 2 in. diameter inside the seating, and is pressed down by the inverted spiral spring B acting upon the opposite end of the bent lever C, the effective length of lever being 2½ in. at the valve and 1¾ in. at the spring. When the valve rises, the bearing point of the spring at the end of the lever, being inclined downwards at an angle of 35° from the vertical

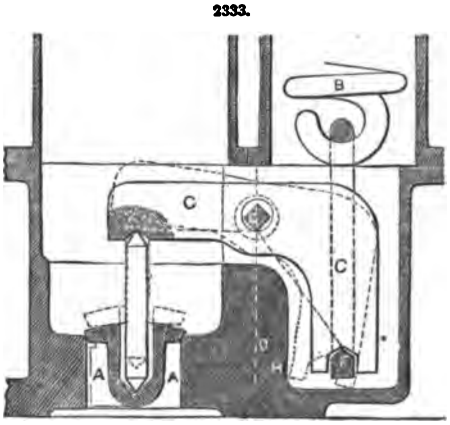
2331.



2332.



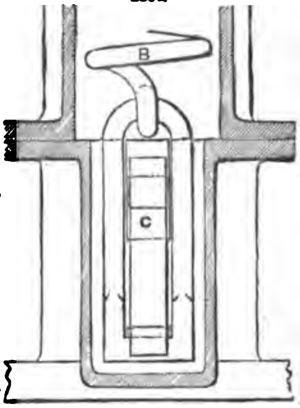
2333.



line D in Fig. 2333, is deflected nearer to this vertical line by the lifting of the valve end, as shown by the dotted position in Fig. 2333; and the result is that the effective leverage at which the spring acts is reduced to the extent required to compensate for the increased tension of the

spring caused by the motion of the lever, so that the total pressure upon the valve remains unaltered. The centre E on which the lever works is a knife-edge, so as to prevent its action from being interfered with by friction from the heavy pressure upon it, which is nearly double the pressure of the spring: and the connection of the spring to the lever at F is by a knife-edge also, Figs. 2333, 2334, in order to give complete freedom of action to the whole. The spiral spring is made of $\frac{3}{8}$-in. round steel, and the pressure upon the valve is adjusted by screwing up the spring by the nut G, the highest pressure being limited by a solid collar upon the spindle. Any accident from failure of the spring is provided against by the lower end of the lever then coming in contact with the casing at H, Fig. 2333, which prevents any risk of the valve becoming displaced.

2334.



This valve being only 2 in. diameter with a circumference of 6·28 in., the height to which it must be lifted in order to give the same area of discharge as before, $\frac{1}{10}$ of a sq. in., is $\frac{1}{6\cdot28}$ or ·159 in.; and the valve end of the lever being $2\frac{1}{2}$ in. long, this requires an angular movement of the lever of 3° 39′. The angle between the spring end of the lever and the vertical is consequently reduced from 35° to 31° 21′; and taking the horizontal distance $1\frac{3}{4}$ in. or 1·75 in. as the sine of the former angle, the sine of the latter angle will be 1·59 in., making a shortening of ·16 in. in the leverage at which the spring acts. The difference between the cosines of these angles to the same radius, or ·106 in., will be the extension of the spring produced by the same range of motion; and the area of the valve being 3·14 sq. in. the total pressure of the spring to give a pressure upon the valve of 120 lbs. an inch will be 538 lbs. with the original leverage of 1·75 in., and with the reduced leverage of 1·59 in. the total pressure required at the spring is then 593 lbs. Hence an increase of 55 lbs. in the total pressure of the spring has to be produced by the extension of ·106 in. in length caused by the motion of the lever, in order to maintain a constant pressure upon the valve; and this gives 519 lbs. for an inch deflection for the strength of spring required for the purpose.

In practice the spring is adjusted so as to give a slightly reduced total pressure upon the valve when fully open, the pressure the square inch on the valve being made about 4 per cent. less when the valve is blowing off strongly than when the valve is shut; in order to compensate for the effect of the friction of the large quantity of steam passing in that case through the narrow opening of the valve. It has been found by trials with this valve that, when the steam is blowing off very strongly, the pressure within the boiler exceeds the load upon the valve by about 5 per cent.; and therefore by proportioning it as above with 4 per cent. less pressure of the spring upon the valve when open than when closed, the occurrence of any sensible increase of pressure within the boiler beyond the limit at which the valve is set is completely prevented. At the same time it is found that the valve closes again after blowing off strongly, without allowing any sensible fall in the boiler pressure below that limit.

This improved valve therefore effectually provides for the prevention of any increase of pressure occurring under any circumstances in the boiler beyond the intended limit of pressure; and the one valve, although only 2 in. diameter, gives the full area for discharge of the steam obtained with the two large valves ordinarily used. The one valve may consequently be considered as fully equivalent in safety to the two ordinary valves, although it may be preferred still to adopt the precaution of employing two valves.

In the case of the two ordinary safety-valves of 4 in. diameter, having a combined circumference of 25·1 in., and a ratio of leverage of 12·57 to 1, a total increase of pressure of 15·0 lbs. the sq. in. will be caused in giving the required full area of opening of $\frac{1}{10}$ sq. in. for discharge. And with two valves of 3 in. diameter, having a combined circumference of 18·8 in., and a ratio of leverage of 7·07 to 1, the total increase of pressure will be 11·3 lbs. per sq. in.

It appears therefore that, with the ordinary construction of safety-valves, the larger size of valves, instead of giving increased freedom to the discharge of the steam, are actually inferior in this respect to the smaller valves, the two 5-in. valves allowing an increase of pressure of 18·8 lbs. to the inch during the escape of the steam, whilst the two 3-in. valves allow only 11·3 lbs. an inch increase with the same discharge. This arises from the circumstance that the pressure required to hold down the valve increases as its area or as the square of its diameter, whilst its area for discharge increases only as its circumference or directly as its diameter. This result is also not altered in the cases where, instead of using a lever with a spring balance at the end, a large spiral spring is employed pressing direct upon the valve, or between two valves, the pressure of the spring and its motion being then the same as those of the valve, instead of the pressure of the spring being diminished and its motion increased both in the same ratio by the action of the lever.

This valve possesses an advantage over most forms of the ordinary valves, from the circumstance that it is quite impossible for the valve to be tampered with by the engine-driver, so as to increase the pressure beyond the intended limit.

One cause of extra pressure in locomotive boilers occurs when an engine is proceeding with a train, with the steam well up and a good fire, and it is suddenly checked by a danger signal being exhibited, and the engine has to be reversed. In such a case, whilst the fire is generating steam vigorously, the cylinders, instead of using it, are converted into air-pumps, pumping air into the boiler at every stroke. The steam generated must all pass off by the safety-valves, and the pressure often rises considerably above the limit at which they are adjusted.

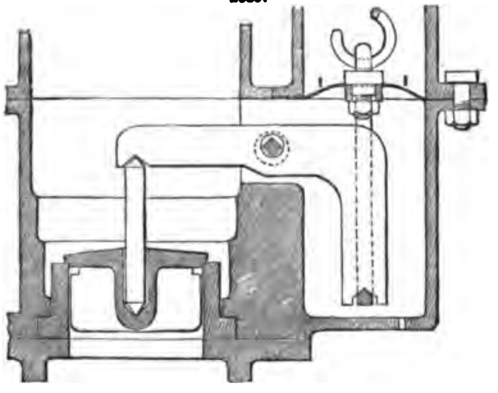
When an engine is taking a heavy load up an incline slowly, the steam blowing off strongly, as

much as 40 lbs. excess of pressure has occurred, without the safety-valves being interfered with. Naylor instances a case of a large goods engine coming to a stand on an incline from want of power, although the steam was blowing off very strongly; and the driver being afraid to go back from fear of a collision, had to secure the valves against blowing off, by pegging down the levers in the slots through which they passed in the weatherboard. The regular working pressure was 120 lbs., but the steam got up to 180 lbs. an inch by the pressure gauge, and the engine was then able to take the train to the top of the incline.

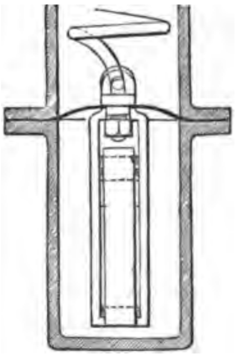
Another source of risk of extra pressure is when an engine is having the steam got up in the engine shed, and to hasten it the steam jet has been put on and left on while the fire-lighter is gone to look after other engines. From a number of experiments Naylor has ascertained that, if the jet be left full on for six minutes after the steam begins to blow off, there will be an excess of pressure in the boiler of at least 30 lbs. a square inch over what the safety-valves on the ordinary construction are loaded at.

In the case of marine boilers it is required by the Government regulations that there shall be at least one safety-valve upon each boiler loaded direct by weights, and that the area of this valve shall be one circular inch for every horse-power nominal; so that a boiler supplying steam equal to 100 horse-power requires a safety-valve 10 in. diameter. But although these valves are loaded by direct weights, the pressure in the boiler will necessarily exceed the load on the valve when the steam is blowing off in great force, which is liable to occur occasionally when the engines are stopped, from neglect in not easing the pressure at that time. There is, however, a serious defect in this mode of loading safety-valves on marine boilers, from the circumstance that when the vessel rolls the pressure of the weight is diminished; and if it rolls to the extent of 45° there will not be more than 70 per cent. of the full load upon the valves at that moment, and consequently there will be a loss of power when the greatest power may be required. Moreover the water in the boiler is subjected to violent commotion by the repeated starts of ebullition from the pressure being suddenly reduced by the lifting of the safety-valve; and this commotion is not at all times stopped by the closing of the valve, but produces priming in the cylinders. With the improved valve, shown by the sections Figs. 2335, 2336, however, the full pressure would be preserved steadily in the boilers, with any extent of rolling of the vessel.

2335.



2336.



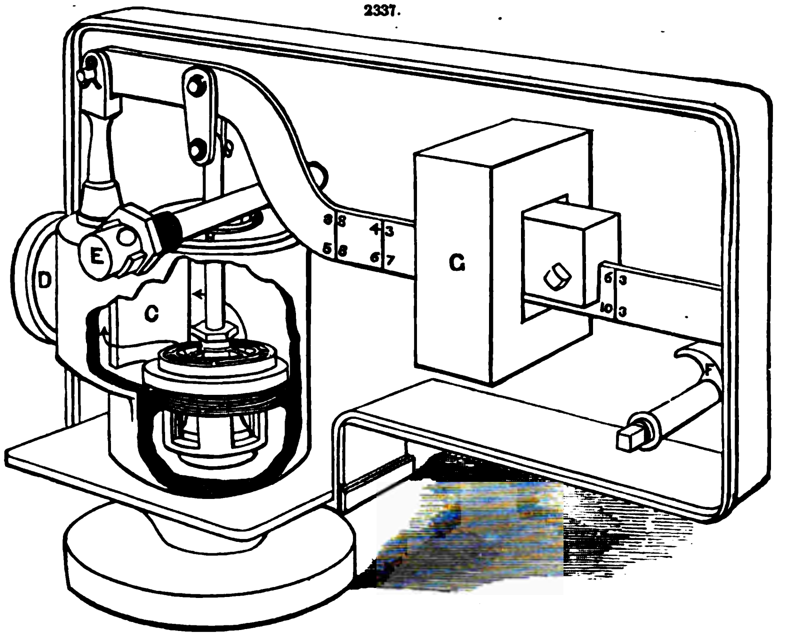
Ashcroft's Lock Safety-Valve.—Fig. 2337 is a perspective view of the valve and its parts, with one side of the case removed, and a portion of the covering of the valve seats broken away, to show the internal construction. Fig. 2338 is an enlarged view of the valve and its seats. The main peculiarities of this valve are in its having a double seat, and offering a much freer egress to the steam than the single disk valve. By reference more particularly to Fig. 2338, these peculiarities may be noticed. The valve itself is hollow, and has an annular space between the two seats, into which, as well as into its central cavity, the steam may pass. The shell that encloses it, and forms its seats, has radial projections, between which are spaces serving as passages for the escaping steam. Fig. 2338 shows the valve lifted from its seat, the arrows showing the direction taken by the escaping steam. A is the valve, and B the seats.

Fig. 2337 shows a guard-plate C, placed in front of the escape pipe D, to prevent tampering with the valve. E is a bolt securing the halves of the case together, and having a hole through it for the reception of the staple of the lock. F is a cam for lifting the lever and the weight G. The cap H, over the valve, serves as a guide to the valve stem, and prevents the steam from escaping into the lock-box.

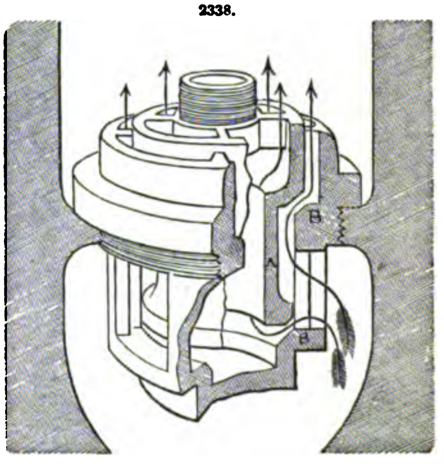
Marine-Engine Governor, invented by Peter Jensen, of Copenhagen.—The engines in very large screw-steamers with deep draught are considered to work with sufficient regularity even in a gale, as the size and weight of the ship to a great extent prevent it from pitching, and for this reason no great difference in the depth of immersion of the screw takes place; but, except in the above case, serious irregularity is experienced in the working of marine engines in a heavy sea, when the screw or the paddle-wheels are one moment deeply immersed and the next moment revolving half or more in the air. A waste of power then occurs; for although in a given time the same amount of power is supplied from the boiler, whatever the speed of the engines may be at any moment, still the power is not exerted in an advantageous manner whenever the propeller is only partially immersed, as it then presents too little surface of resistance to the water, and is consequently not

able to propel the vessel so efficiently as when immersed to the proper depth. In most marine engines, therefore, instead of the consumption of steam being reduced by saving the steam when it

2337.



2338.



cannot be used to advantage in consequence of the propeller being only partially immersed, it is at that time wasted in driving the screw or the paddle-wheels with great speed in a light draught of water, and a great amount of slip or loss in effective speed of the vessel consequently ensues. In applying a governor to marine engines economy of power must result, as in the case of stationary engines. Moreover, most of the accidents occurring to marine engines are due to the sudden shocks that will happen during a gale even in well-balanced engines. The lubrication is also often rendered difficult, because the oil is thrown out of the cups; and the great amount of wear and tear in marine engines may be attributed partly to the shocks and the irregular motion, and partly to the more imperfect lubrication.

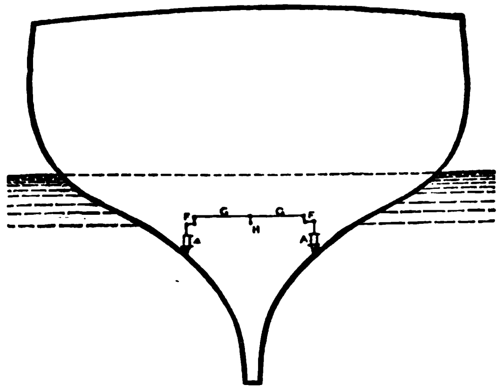
Marine-engine governors have been attempted on several occasions, but only very few are yet applied. An ingenious modification of the ordinary Watt's centrifugal governor has been employed for this purpose, Silver's four-ball governor, in which the action of a spiral spring is substituted for that of gravity, and the whole apparatus is balanced so as to remain undisturbed in action during the pitching of the vessel. But the mode of action of all such governors is by checking the supply of steam to control the speed of the engine *after* it has begun to change either to quicker or slower; and it has appeared to the inventor of the governor forming the subject of the present paper, that the principal desideratum in a good marine-engine governor is an instantaneous action, so that whenever the screw or the paddle-wheels are going down in the water more steam may be admitted to the engines as quickly as possible, and in the opposite case the admission of steam may be as quickly as possible checked, *before* the speed of the engines has been sensibly affected. For attaining this object it seems more natural to make use of the cause of the evil as a remedy against it, or to employ the irregular motion of the vessel as a means of regulating the engines, than to let the engines regulate themselves. By this means an intermediate step is dispensed with; and by making use of the non-elastic water as the motive power of the governor, the action will be exerted quickly enough upon the engines to regulate the supply of steam before the depth of immersion of the propeller has been materially altered by the pitching of the vessel.

The construction of Jensen's marine-engine governor is shown in Figs. 2339 to 2341. Fig. 2339 is a transverse section of the vessel showing the governor in position; and Figs. 2340, 2341, are a longitudinal section and elevation of the governor enlarged.

A cylinder A is placed at each inner side of the vessel below the water-line, the bottom of the

cylinders communicating with the water outside by means of the Kingston valves B. Each cylinder is fitted with a piston C, which is loaded with a spring D either of steel, compressed air,

2339.



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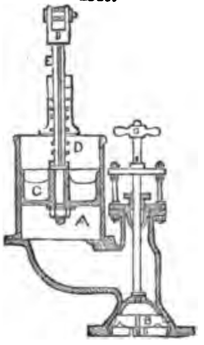
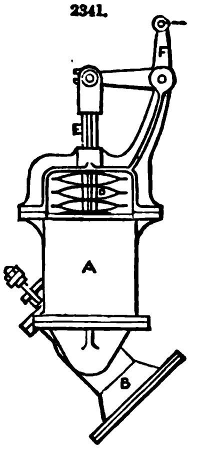


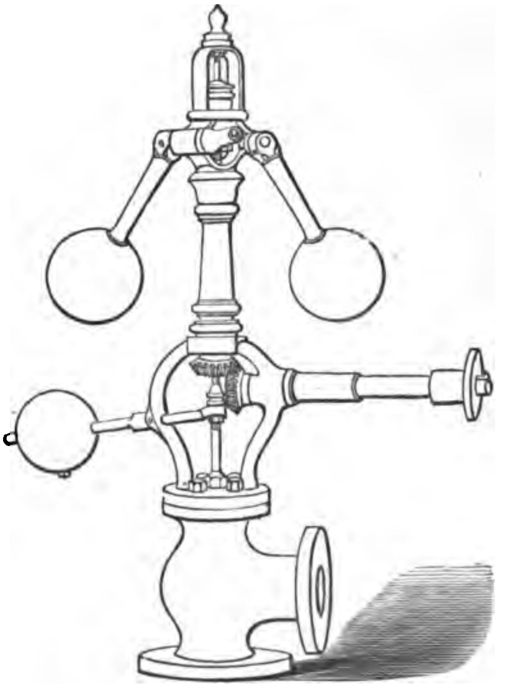
2341.



or india-rubber. The piston-rods E act upon bell-crank levers F F, and by means of connecting-rods G G motion is given to a common spindle H, from which the throttle valves of the engines are worked in such a manner that when the pistons C go down the throttle valves are closing, and when the pistons go up the valves are opening. Now as the pressure of the external water increases in proportion to the depth, when the openings of the valves B come into different depths in consequence of the pitching or rolling of the vessel, the pressure on the pistons C will be changed proportionately; and to each pressure will correspond a certain position of the pistons and of the throttle valves connected with them. Omitting the pitching of the vessel in a paddle-wheel steamer and considering only the rolling motion, it is obvious that when one paddle-wheel is deeply immersed and the other nearly or entirely out of the water, the pressure on the two pistons will be different; but supposing them connected together, the position of both and of the throttle valves will be then corresponding to the difference of resistance on the two paddle-wheels.

If these cylinders are placed as near to the propeller as convenient, so as to ensure pretty nearly the same depth of immersion, it will be seen that this apparatus will then act as a governor for the engines; for when the propeller is revolving in a light draught of water, the supply of steam to the engines is proportionately diminished; and when revolving in deep water, the supply of steam is proportionately increased.

2342.

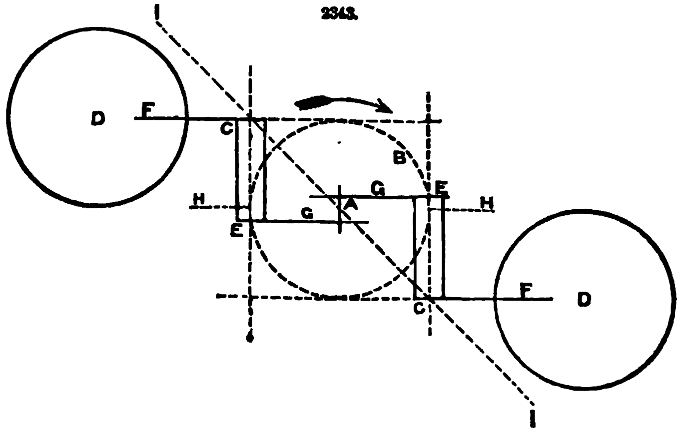


Harmonizing Governor, Fig. 2342.—The nature of this invention consists in swinging the balls of a centrifugal governor, at an angle to a radial line, harmonizing with and corresponding to the motion of said balls, in such manner that the inertia, the momentum, and centrifugal force, all act in favour of the governor, instead of against it, as is the case in the ordinary centrifugal governor. *Angular Motion*, p. 101.

This is illustrated in Fig. 2343. A circle B is struck, of nearly the size of the ball. A square is then formed by drawing lines tangentially with the circles, as shown by dotted lines. This square gives the plan of the governor. C is the point of suspension of the arm; the line from C to D represents the arm, as also the direction of the swing of the ball. The lines from C to E constitute the centres of the pins upon which the arms F and links G are firmly fixed. The pins connecting F and G turn freely in sockets C E. Links G form a connection with a stem passing through the centre of the valve. Links G may also turn outward, as shown at H, and form a connection with a sliding sleeve. The sockets C E are firmly secured to the shaft giving them motion. The angle of the plane in which the balls swing is indicated by the dotted radial line I. Balls vibrating at

this angle will swing freely whether moving quickly or slowly; if moved slowly, they will be acted upon by but little centrifugal force, and will swing low and perfectly free from the points of suspension; if moved quickly, they will be acted upon by greater centrifugal force, and will swing

2343.



higher and farther out, though quite freely, without causing the least binding or friction at the joints, by which the arms are suspended. The balls are at liberty to fall to the rear of the points of suspension, or to gain upon said points, according as the force of their inertia or their momentum predominates. By this arrangement we obtain a governor the most simple and cheap of construction, beautiful in form, and in action, durability, and efficiency the most complete.

The Valve.—Much difficulty is experienced from improperly-constructed valves, many valves being so constructed that large surfaces slide upon and against each other. The contact of these surfaces is expected to be steam-tight, and yet freely move against each other. This is a mechanical impossibility; if such valve is anything like steam-tight, it will require a great force to move it; and should it gum or expand the least, it will stick so tight as to require a sledge to move it. If it is made to move freely, steam will pass between the surfaces, and in a short time cut a passage around the valve, instead of passing through it. Such valves should never be put on engines. The valve attached to this governor is so constructed that its opening and closing do not depend upon surfaces moving upon or against each other, but upon surfaces moving towards and from each other. The impact of the passing stream is not upon and over the surfaces that are depended upon for closing the valve, consequently the cutting of the valve by the steam will never cause it to leak. The valve has two steam passages perfectly balancing each other. The steam can never make for itself false passages, as there are no joint or openings but the proper passages for the steam.

Graduating Valves.—An idea has been entertained that a valve should have an increased opening, tapering towards a point. Such valve will, as is intended, supply steam to the engine in a ratio differing from that of the action of the governor. To graduate the quantity of steam to the engine is especially the office of the governor, and any attempt to effect it in the valve acknowledges the deficiency of the governor. If the valve openings are proportioned to the supply-pipe, a good governor will do all the graduating. The effect of a taper valve is but to lengthen the throw of the valve. This becomes necessary from the defects of the radial centrifugal governor, as it never acts at the proper time and always with a plunge beyond the proper point. For this reason the valve openings are made close, requiring a long throw, so that the defective governor will not at one moment cut all the steam off, and the next throw it all on. Hence a graduating valve.

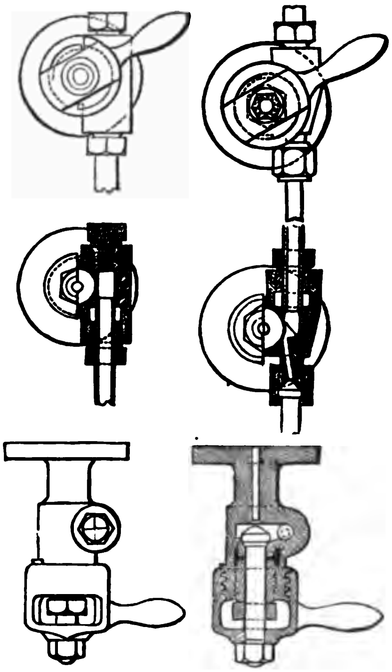
The Governor as a Cut-off.—A good governor combined with a properly-constructed valve constitutes perhaps the best variable cut-off made. The capacity of the valve should equal that of the pipe; the openings should be perfectly straight across without the least taper. Such a valve will require but very little throw, and a governor acting positively and simultaneously with any change of speed in the engine will either cut off all the steam when required, or give the boiler pressure of the steam from a change of speed impossible to be detected by the eye. With the usual variable cut-off the steam may be cut off near the beginning of the stroke, and no steam can be admitted until the beginning of the next stroke. If a heavy load be thrown on the engine immediately after the steam is cut off near the beginning of the stroke, the speed of the engine will be dragged down before steam can be admitted after passing the centre.

Locomotive-Boiler Mountings designed by W. Stroudley.—Figs. 2344 to 2352 illustrate a number of examples of locomotive-boiler mountings of patterns which have been successfully used for some time past by W. Stroudley, the locomotive superintendent of the Highland Railway, and which have also been adopted on other lines. The main features in these mountings are the external screws by which the cocks are closed and opened, and the arrangement of double-faced valves which render packing unnecessary. Referring to Fig. 2344, for instance, which represents a set of gauge-glass fittings, it will be seen from the sectional plan that the conical back of the valve when the latter is open makes a tight joint against a face provided for it, and thus prevents the passage of the steam or water past the valve spindle. In this instance, also, the back seating of the valve is, in the case of the lower fitting, so constructed that when the valve is screwed partially forward, a communication is opened between the gauge-glass and the waste-pipe. The screw by which the valve is moved is square-threaded, and is 2 in. in diameter outside, and ¼-in. pitch. From its

position it can be readily oiled and kept in order, and as its threads have ample surface, the wear that goes on is very small.

Fig. 2345 shows an injector steam-cock with a clear bore of $1\frac{1}{8}$ in., and as in this case it is desirable that the cock may be opened quickly, the screw, which is $2\frac{3}{8}$ in. in diameter outside, is double threaded, and is of $\frac{3}{4}$-in. pitch. Another smaller injector steam-cock with $\frac{3}{4}$-in. bore, is shown by Fig. 2347, the opening screw, which is double threaded in this case also, being $2\frac{1}{4}$ in. in diameter outside, and $\frac{1}{2}$-in. pitch. The tallow cock shown by Fig. 2346, the blow-off cock shown

2344.



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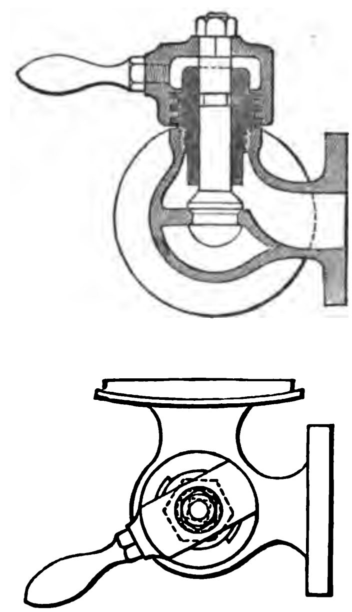

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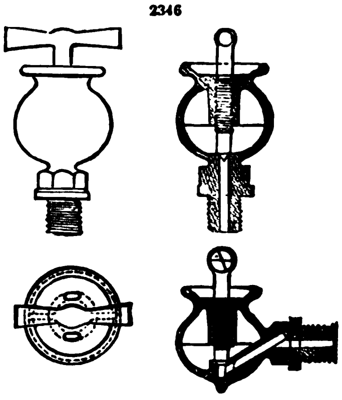

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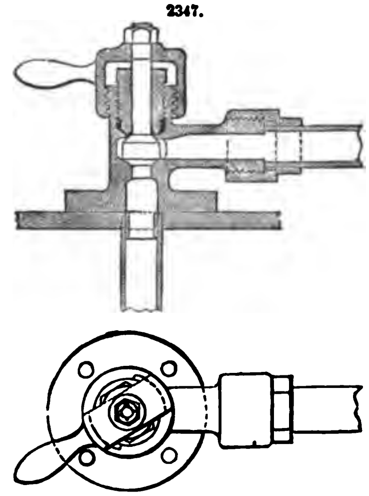
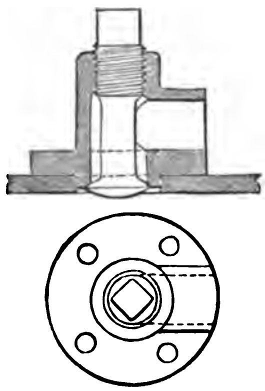


by Fig. 2348, and the blow-cock, gauge-cock, and mud-plug, represented by Figs. 2350, 2351, and 2352 respectively, will require no special description, as their construction is clearly shown by the engravings. We may, however, point out that in the case of the blow-off and gauge cocks, Stroudley uses V-threaded screws.

In the case of the clack-box shown by Fig. 2349, it will be noticed that Stroudley places the joint face on the under-side of the screw, and the steam and water are thus prevented from getting

access to the latter. By this means all the difficulties incidental to screwed covers of the ordinary kind, such, for instance, as the sticking and furring up of the screws, is avoided, and Stroudley found that the covers thus constructed suited well.

2348.



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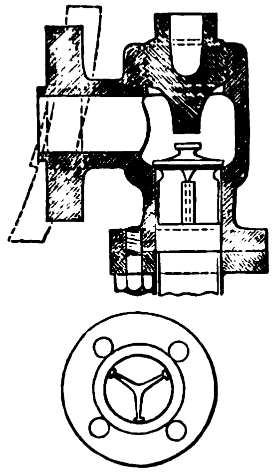
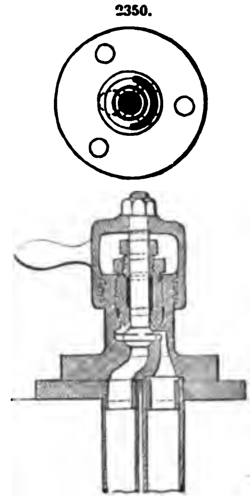


2350.



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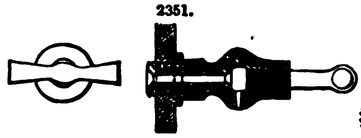

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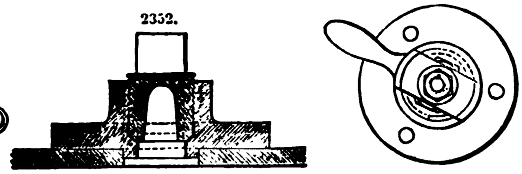
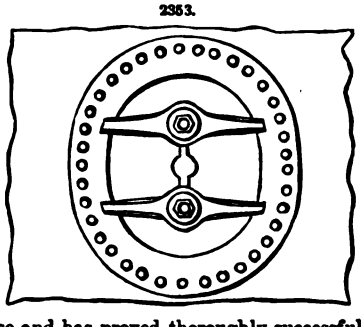


Manhole Cover.—It is not entirely to the amount of metal cut away that the weakness of an unguarded manhole is due · the action of the cover plays an important part in the matter. The covers are generally placed internally, and are held up by the steam pressure within, as well as being suspended from arched bridges outside by bolts and nuts. The joint is very seldom a good one, the curve of the cover does not always follow that of the boiler, and as the surfaces of the plates at the joint are not dressed smooth so as to make a tolerably tight joint, a considerable strain is frequently brought on the bolts. Hence we get the bolts pulling and the steam pushing at the plate, the result of the joint action tending, of course, to force the cover through the manhole, and rend the boiler plates. The importance of strengthening the manhole with a mouthpiece and otherwise rendering it safe is therefore very apparent; it is a remedial or rather a preventive measure, very easy of adoption. To this matter Joseph Ride has given his attention, and has invented an improved manhole cover which we illustrate, Figs. 2353, 2354. This cover has been

2353.



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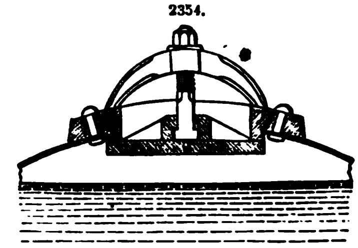


in use and has proved thoroughly successful. The cover fits against the inside with a faced joint, and cannot be taken off while there is any pressure of steam in the boiler; and the strong ring, forming the outer part, strengthens the shell of the boiler, thus preventing accident through fracture of the manhole plate of the boiler.

A Manometer is an instrument for measuring the rarity, or, what amounts to the same thing, the elastic force of gases, and especially that of steam in boilers. There are three principal kinds; *free air*, *compressed air*, and *metallic* manometers.

A free air manometer is an inverted siphon A M B, Fig. 2355, one end A of which opens into the boiler and the other end B into the air. The lower portion of the tube is filled with mercury up to a height C or C′ which is the same in both branches so long as the pressure in the boiler is

equal to the pressure of the atmosphere. But if the pressure of the steam exceeds one atmosphere, the level sinks by a certain quantity C D in the adjacent branch, and rises in the other branch by a quantity C′ D′, which is equal to C D if the diameters of both branches are equal. The excess of the pressure of the steam over that of the atmosphere is measured by the difference of level in the two branches; and if we denote the pressure of the steam to the square mètre by P, that of the atmosphere by P_0, the weight of the cubic mètre of mercury by Π, and the height D D′ by $2h$, we have

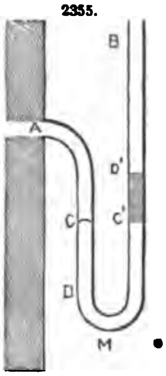
$$\frac{P}{\Pi} = \frac{P_0}{\Pi} + 2h. \qquad [1]$$

The quotients $\frac{P}{\Pi}$ and $\frac{P_0}{\Pi}$ express the heights of the columns of mercury, the weight of which would be equivalent to the pressures P and P_0; calling these H and H_0, we may write

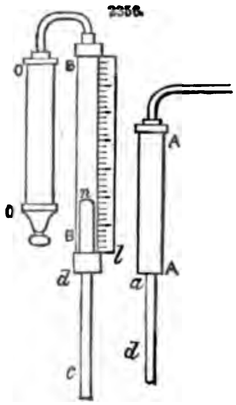
$$H = H_0 + 2h. \qquad [2]$$

The employment of this kind of manometer is prescribed in France by the administrative regulations of 1843. It is, however, open to the objection of requiring a great height when the pressure in the boiler is considerable, for the distance D D′ must be equal to as many times $0^m \cdot 76$ as there are units in the number of atmospheres expressing the excess of the measured pressure above that of the atmosphere. Since the date above alluded to, MM. Thomas and Laurens have removed this defect by giving the ascension tube a greater diameter than the rest of the manometrical tube. This arrangement is represented in Fig. 2356; *a b* and *c d* are the two branches of the iron siphon from 5 to 6 millimètres in diameter. The branch or arm *a b* which communicates with the boiler is surmounted by a cast-iron cylinder A A, which receives the condensed steam, and which is always filled with water. The arm *c d* is surmounted by a tube of thick glass B B, the inner section of which is five or six times greater than that of the siphon; affixed to this tube is a graduated scale *l l*. In communication with the upper portion of the tube is an iron pipe D D, closed at the bottom and pierced with an orifice O in its upper portion. This pipe is intended to receive the mercury in case the excess of pressure should raise the level *n* above the ordinary limit and force the liquid out of the tube B B. The effect of the enlarged section in the upper part of the siphon is obvious. If, for example, the section of the tube B B is five or six times greater than that of the arm *a b*, when the increased pressure forces the mercury down this arm by a quantity *h*, it will rise in the tube B B only $\frac{1}{5}h$; and the manometer thus modified will require much less space. Formula [2] may be easily modified to render it applicable to this arrangement; but it is better to graduate the scale *l l* by means of a standard manometer.

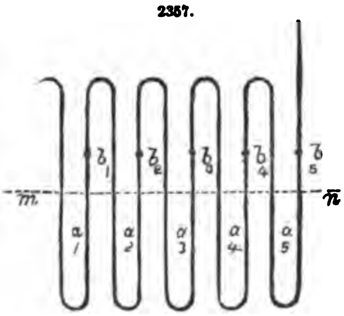
2355.



2356.



2357.



Richard has adopted another arrangement for reducing the height of the manometer, founded upon a principle long known, but which he has happily applied. This arrangement consists in bending the tube a number of times, as shown in Fig. 2357. In the natural state, that is, when the pressure in the boiler is equal to the atmospheric pressure, all the tubes are filled with mercury in their lower portions up to the same level *m n* which divides them into nearly two equal parts, and the upper curves are filled with water. When the pressure in the boiler increases, the level of the mercury in the adjacent tube sinks by a quantity *h* and stands at a_1; it rises in consequence in the next branch by an equal quantity and stands at b_1; it sinks by *h* in the third branch and stands at a_2; it rises by *h* in the fourth and stands at b_2; and so on through the other branches, till it stands in the last at b_5. Let P_1, P_2, P_3, ..., be the values of the pressures to the mètre at the points $a_1, a_2, a_3, \ldots$; P_1, P_2, P_3, ..., the values of the pressure at the points $b_1, b_2, b_3, \ldots$; Π the weight of the cubic mètre of mercury, and Q the weight of the cubic mètre of water. Considering the levels a_1, b_1, a_2, we shall have $P_1 = p_1 + \Pi . 2h$ and $P_2 = p_1 + Q . 2h$, whence

$$P_1 - P_2 = (\Pi - Q) . 2h.$$

We find in like manner

$$P_2 - P_3 = (\Pi - Q) . 2h,$$
$$P_3 - P_4 = (\Pi - Q) . 2h,$$
$$P_4 - P_5 = (\Pi - Q) . 2h;$$

whence adding member by member,

$$P_1 - P_5 = 4(\Pi - Q) . 2h.$$

We have again

$$P_5 - p_5 = \Pi\, 2h,$$

or

$$\frac{P_1}{\Pi} - \frac{p_5}{\Pi} = 2h\left[1 + 4\left(1 - \frac{Q}{\Pi}\right)\right],$$

or, substituting for $\frac{Q}{\Pi}$ its value $\frac{1}{13 \cdot 6}$,

$$\frac{P_1}{\Pi} - \frac{p_5}{\Pi} = 2h\,[1 + 4 \times 0 \cdot 926], \qquad [3]$$

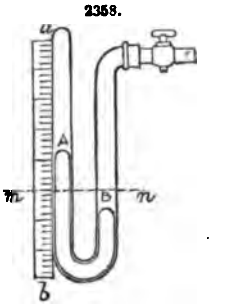
a formula which will enable us to calculate the pressure P_1 of the steam knowing the height h, or to determine, on the contrary, this height knowing the pressure P_1. It may be remarked that the number 4 which multiplies $1 - \frac{Q}{\Pi}$ is the number of the lower curves of the tube diminished by unity; so that calling this number of curves n, the height of the mercury measuring the pressure in the boiler H and that measuring the atmospheric pressure H_0, we shall have generally

$$H = H + 2h\,[1 + 0 \cdot 926\,(n - 1)]. \qquad [4]$$

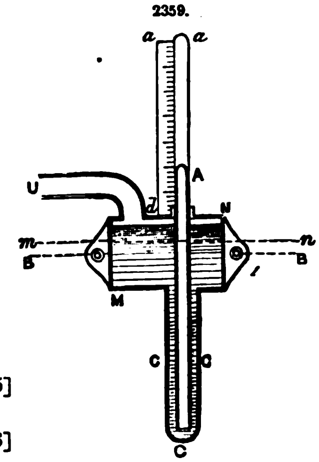
A compressed-air manometer is also an inverted siphon, having one arm closed while the other is in communication with the boiler. Fig. 2358 represents the usual arrangement of this apparatus.

When the pressure in the boiler is equal to the pressure of the atmosphere, the mercury is at the same level $m\,n$ in the two arms. When the pressure increases in the boiler, the level is depressed by a quantity h in the adjacent arm, and stands at B, it is, consequently, raised by an equal quantity in the other arm and stands at A, the air in this arm being compressed by the rising of the mercury. If P denote the pressure in the boiler, and P_0 the pressure of the atmosphere, we have first as the pressure at A after compression, $P_0 \frac{Y}{Y - h}$, Y representing the height of the closed tube above the level $m\,n$. Consequently,

2358.



2359.



$$P = P_0 \frac{Y}{Y - h} + 2\,H\,h,$$

or

$$\frac{P}{\Pi} = \frac{P_0}{\Pi}\,\frac{Y}{Y - h} + 2h, \qquad [5]$$

or

$$H = H_0 \frac{Y}{Y - h} + 2h, \qquad [6]$$

a formula enabling us to calculate H or h knowing one of these quantities.

The closed arm is provided with a scale $a\,b$, which may be graduated by means of formula [6] or by comparing it with a standard manometer.

These compressed-air manometers are sometimes arranged, as shown in Fig. 2359. M N is an iron receptacle communicating with the boiler through the pipe U. This receptacle is provided on its lower side with a kind of bulb C C C, into which the manometrical tube D D, which is closed at the top, plunges. The receptacle being partly filled with mercury, the pressure of the steam depresses the level of the mercury in the receptacle by forcing it up through the tube which is provided with a scale $a\,b$. Supposing $m\,n$ the level of the mercury when the pressure in the boiler is equal to the pressure of the atmosphere, if the level sinks by z in the box M N, it will rise by $n\,z$ in the tube, n denoting the ratio of the sections, Ω and ω of the box and of the tube. We shall have, therefore, $P = P_0 \frac{Y}{Y - n\,z} + (n + 1)\; z\,.\,\Pi$, or making $n\,z = h$, dividing by Π and substituting for n its value $\frac{\Omega}{\omega}$,

$$\frac{P}{\Pi} = \frac{P_0}{\Pi} \cdot \frac{Y}{Y - h} + \left(1 + \frac{\Omega}{\omega}\right) h,$$

or again,

$$H = H_0 \cdot \frac{Y}{Y - h} + \left(1 + \frac{\Omega}{\omega}\right) h. \qquad [7]$$

The indications of the manometer ought strictly to undergo correction relative to the change of temperature. But, as a variation of 15° occasions an error of only $\frac{1}{18}$, and as extreme accuracy in measuring the pressure is never necessary, this source of error is usually neglected. Yet, if is be required to take the temperature into account, we may proceed as follows;—

Taking the arrangement of Fig. 2359, let y be the volume occupied by the compressed air at a given moment, or the number of divisions which it occupies in the tube, and p the pressure of this gas to the square mètre. We shall have, putting t for the temperature and a for the

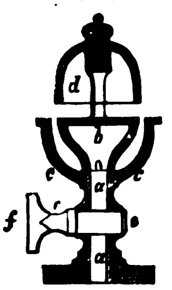
coefficient of expansion, $p = 10334^k \cdot \frac{Y}{y}(1 + a\,t)$, Y being the volume of the same gas at zero and under the pressure of $0^m{\cdot}76$ of mercury. Let H be the height of the column of mercury above the level of the bulb. This height, observed at the temperature t, would be at zero $\frac{H}{1 + \frac{t}{5550}}$ or $\frac{H}{1 + 0{\cdot}00018\,t}$. The weight of a column of mercury having this height and a base of 1 square mètre would be $\frac{13598^k \cdot H}{1 + 0{\cdot}00018\,t}$, which is the pressure exerted upon 1 square mètre by the column in question. Hence we have $P = 10334^k \cdot \frac{Y}{y}(1 + a\,t) + \frac{13598^k \cdot H}{1 + 0{\cdot}00018\,t}$, and as the number 10334 is the product of 13598 by 0·76, we may write

$$P = 10334^k \left[(1 + a\,t)\frac{Y}{y} + \cdot \frac{H}{0{\cdot}76} \cdot \frac{1}{1 + 0{\cdot}00018\,t}\right]. \qquad [8]$$

If Y is unknown, it may be determined by experiment, using this very formula [8]. For this purpose we must put the bulb in communication with the atmosphere, observing at the same moment the barometer. P is then equal to the pressure of the atmosphere; we observe y, H and t; all is then known in the formula except Y, the value of which we may thus determine once for all. If Z is the barometrical height observed, we have $P = 10334 \cdot \frac{Z}{0{\cdot}76}$; substituting this value, the number 10334 vanishes from the formula, which enables us to find Y more easily.

The compressed-air manometer is open to a grave objection; the oxygen of the air contained in the manometrical tube is gradually absorbed by the mercury, which becomes oxidized; the volume of compressed air diminishes, and the instrument indicates too great a pressure. The gas having no influence upon the mercury, might be substituted for the air. But their fragility and great cost have led to the gradual abandonment of air manometers, and to the substitution of a less accurate instrument, but one that is less liable to injury and much cheaper, namely, the metallic manometer.

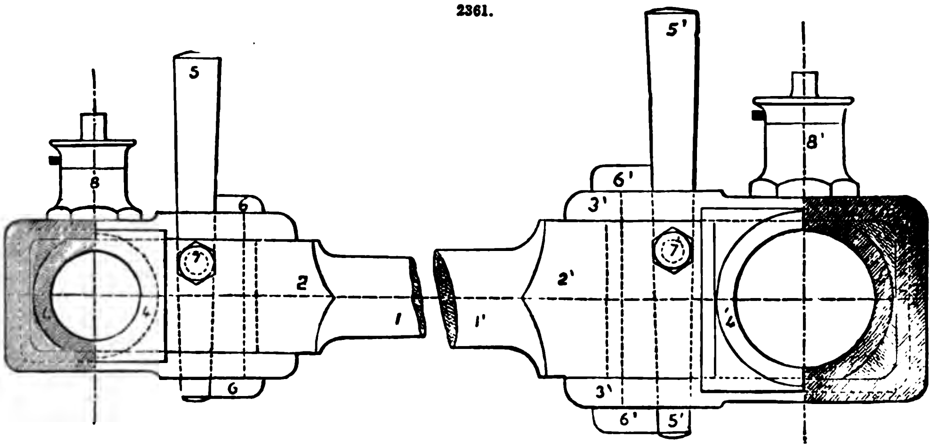
2360.



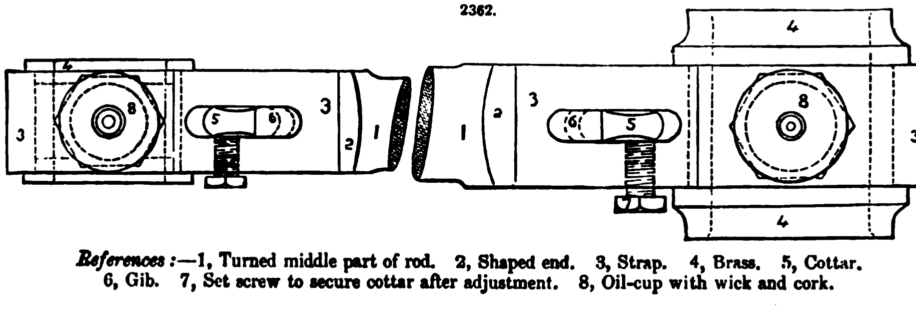
Steam Whistle.—An apparatus attached to a steam-engine, through which steam is rapidly discharged, producing a loud shrill whistle, which serves as a warning or signal. In Fig. 2360, a is a tube, b hollow piece, $c\,c$ cup, d thin brass cup, and $e\,f$ stop-cock. The steam issues from a narrow annular orifice around the upper edge of the lower cup or hemisphere, striking the thin edge of the bell above it, and producing sound in the manner of an organ-pipe or common whistle.

Connecting-Rod for Clayton and Shuttleworth's Portable Engine, see p 33.

2361.



2362.

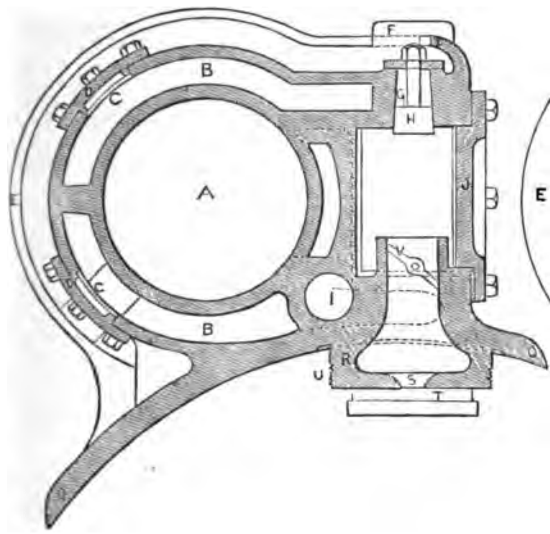


References:—1, Turned middle part of rod. 2, Shaped end. 3, Strap. 4, Brass. 5, Cottar. 6, Gib. 7, Set screw to secure cottar after adjustment. 8, Oil-cup with wick and cork.

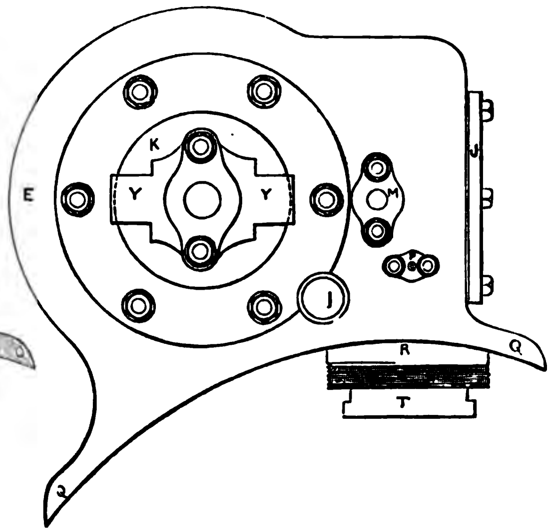
The large and small ends of this connecting-rod, Figs. 2361, 2362, being similar, differing only in size, the same figures are put to denote similar parts at either end.

Cylinder with Steam-Jacket for Clayton and Shuttleworth's Portable Engine, Figs. 2363 to 2366.

2363.



2364.



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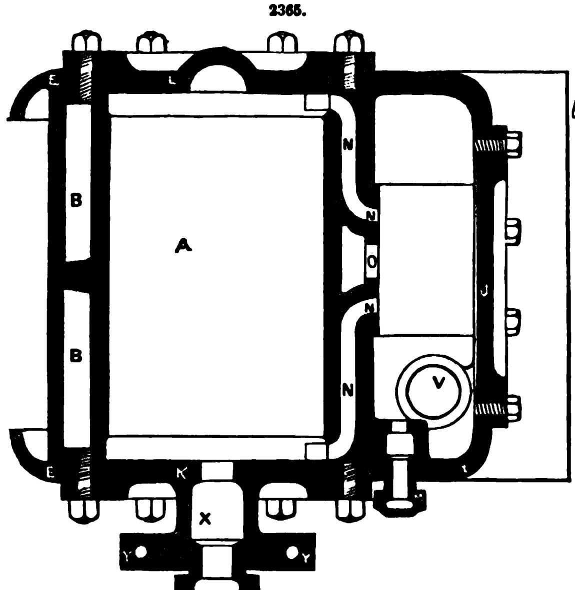
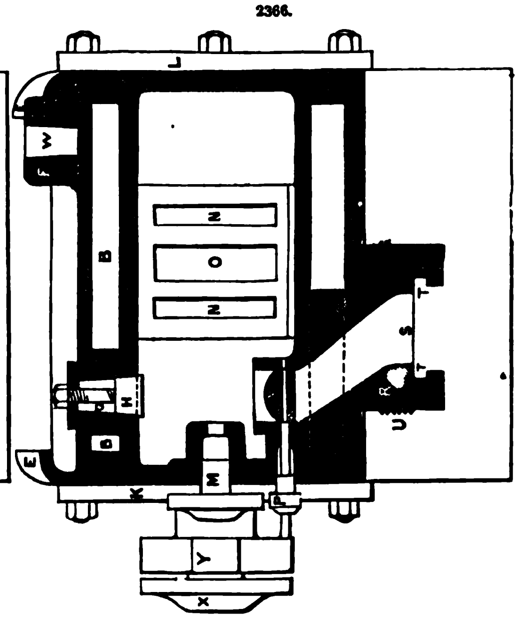


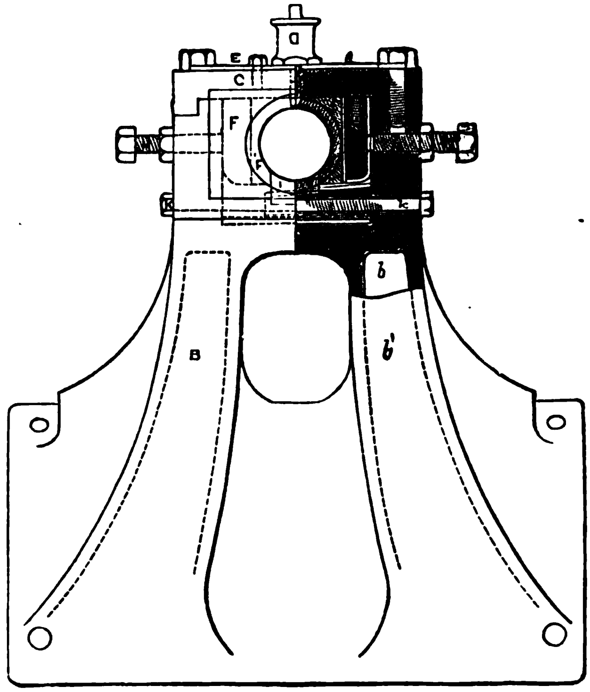
2366.



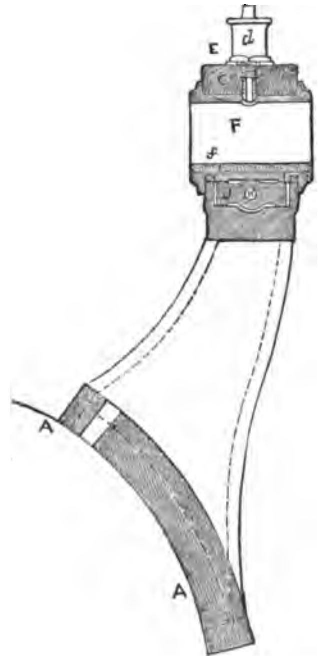
References:—A, Cylinder. B, Steam-jacket. C, Openings for removing the core, provided with steam-tight covers D. E, Projecting flanges to hold the cylinder from lagging. F, Contains socket W for receiving the chimney rest. G, Opening giving access for boring out the steam-pipe in which the throttle valve works. H, Conical plug for closing G steam-tight. I, Exhaust passage. J, Steam-chest cover. K, Front cylinder cover, with gland X for piston-rod and projection Y, to which the slide bars are bolted. L, Back cylinder cover. M, Gland for slide-valve spindle. N, Steam ports and passages. O, Exhaust port. P, Gland for throttle-valve spindle. Q, Bottom of cylinder casting planed to segment of circle to fit barrel of boiler. R, Cylindrical part carrying the stop-valve port S, and having grooves T for stop. T, Valve to slide in. Part R projects through into boiler. U, Screw thread chased on part R for securing the cylinder to the boiler by means of a ring nut, in addition to the usual bolts which pass through the bottom flanges Q. V, Throttle valve. W, Socket for chimney rest. X, Piston-rod gland. Y, Projections from front cylinder cover, to which the four slide bars are bolted.

Crank-Shaft Bracket, Clayton and Shuttleworth's Portable Engine, Figs. 2367, 2368.

2367



2368.

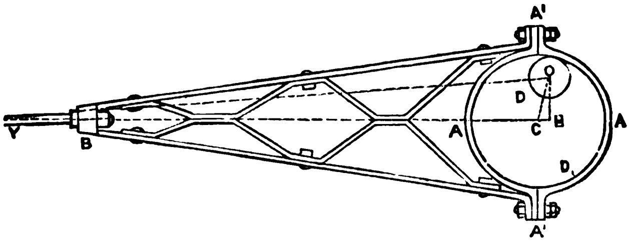


References:—A, Under part of bracket, planed to segment of circle to fit barrel of boiler. *b*, B, Cellular; the parts of which are arranged to give strength and lightness. *c*, C, Cap of bracket. *d*, D, Oil-cup fitted with wick and cork. *e*, E, Thin plate to lock the bolts which fasten the cap *c*, C. *f*, F, Side brasses. *g*, Packing pieces, one to each side brass. *h*, H, Set screws for adjusting side brasses *f*, F. I, Bottom brass. J, Wedge for adjusting bottom brass. *k*, K, Screw bolts for moving adjusting wedge J.

Eccentric.—A contrivance for converting a continuous circular motion into a reciprocating motion. There are several kinds of eccentrics; the *circular*, or eccentric, properly so called, and various other contrivances bearing the name of excentrics, but which are really cams, such as the *heart-shaped eccentric*, the *triangular eccentric*, *eccentrics with a uniformly varied motion*, and so on.

The circular eccentric consists of a circular disc D, Fig. 2369, usually hollowed to diminish its weight. This disc turns about an axis O, perpendicular to its plane, but which does not pass through the centre of the figure C, whence its name excentric. The disc is enclosed by a ring A A, called an *eccentric strap*, moving freely upon the circumference of the disc and connected by rods A′ B, A′ B, called *eccentric rods*, with the extremity B of the piece to which it is required to give a reciprocating motion in the straight line X Y passing through the point O, in the plane of the disc. The distances O C and B C remaining invariable, the point B moves upon the straight line X Y, as if it were connected by means of a connecting-rod of a length B C, to a crank having a length O C and its centre in O. In other words, the circular eccentric is only a variety of the arrangement denoted by the terms connecting-rod and crank. The law of motion will, therefore, be the same; that is, if we draw O H perpendicular to X Y, terminating it at B C produced, we shall have, putting u for the velocity of the point C, and v for that of the point B,

2369.



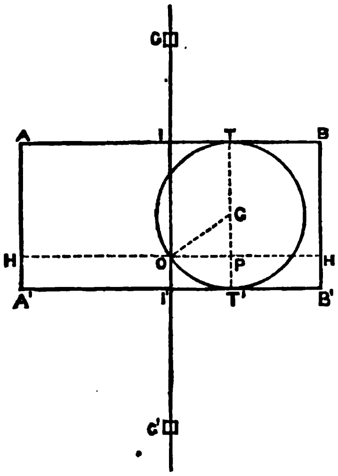
$$\frac{v}{u} = \frac{\mathrm{O\,H}}{\mathrm{O\,C}}; \qquad [1]$$

so that if u is constant, v is proportional to O H.

The circular eccentric is employed in steam-engines to work the slide-valves. The large amount of friction produced between the sheave and its strap renders the application of this eccentric impracticable in cases in which it is required to transmit a great force. The same may be said of all contrivances bearing the name of eccentrics; they are applicable only when the force to be transmitted is small.

Another way of employing the circular disc to produce a reciprocating motion is to make it turn about a point O, Fig. 2370, taken on its circumference; and, instead of enclosing it in a ring, it is made to revolve in a rectangular frame A B, A′ B′, with two parallel sides of which it is constantly in contact. A rod fixed in the middle I and I′ of these sides, and passing between guides G and G′, receives thus a reciprocating motion the extent of which is the diameter of the disc. The law of the motion is easily obtained. Let ω be the angular velocity of the disc, and r its radius. Taking the disc in any position, draw, through the centre of rotation O, O H perpendicular to G G′, or parallel to the sides A B, A′ B′; and through the centre C of the disc draw T T′ parallel to G G′, or perpendicular to the above-mentioned sides. The points T and T′ will be the actual points of contact of the disc with the frame. If P is the point of intersection of the straight lines O H and T T′, it is plain that we shall obtain the law of the motion by expressing the distance T P as a function of the time t, reckoned, for example, from the instant when the point C was upon the straight line O H. But we then have $\text{C O P} = \omega t$; consequently

2370.



$$\text{T P} = \text{T C} + \text{C P} = r\,(1 + \sin.\,\omega t). \qquad [2]$$

Such is the law which it was required to obtain. It will be readily perceived that the distance T P varies between zero and $2\,r$. The advantage of this eccentric is, that the changes of velocity take place gently, and that the disc always acts normally to the sides of the frame or case. It would, however, give rise to a considerable amount of friction if the force to be transmitted were not small.

Eccentric Strap, Fig. 2369.—The revolution of the eccentric in its strap causes an amount of friction that must be considered; the resistance caused by this friction is, however, easily calculated. If T represent the tension or the pressure exerted by the eccentric rod, the friction of the strap against the circumference of the eccentric will be represented by $f\,\text{T}$, f denoting the coefficient of friction; $d\,s$ being the element of the inner circumference of the strap, the elementary work of the force T will be $f\,\text{T}\,d\,s$, and the expression of its total work for one revolution of the eccentric will be $\int_0^{2\pi r} f\,\text{T}\,d\,s$, r denoting the inner radius of the strap. As the force T is not given analytically as a function of s, this definite integral must be calculated by Simpson's approximative formula, having determined an even number of values of T corresponding to values of s in arithmetical progression. For this purpose we may trace the eccentric and its rod in a certain number of positions, embracing altogether a whole revolution of the eccentric. For each of these positions we determine the force T, and, consequently, the friction $f\,\text{T}$; computing, at the same time, the arc s of the inner circumference of the strap included between the point of contact of the strap and of the eccentric for each of the positions considered, and the point of contact corresponding to the initial position. We may then trace two rectangular axes, representing as abscissæ the values of s, and as ordinates the corresponding values of $f\,\text{T}$. The area of the continuous curve drawn through the ends of these ordinates will express the force sought. If the values of s are not in arithmetical progression, having traced the curve as described above, we may divide the extreme abscissa—that is, $2\,\pi\,r$—into an even number, $2\,n$, of equal parts; raising ordinates through the points of division till they meet the curve, and measuring them on the plan, we obtain the ordinates which are to enter into Thomas Simpson's formula.

The first factor of this formula will be $\frac{2\,\pi\,r}{2\,n}$, a quantity proportional to r; it follows from this that the amount of work consumed by the friction of the strap increases with the inner radius of the strap. On account of the large amount of friction produced, this mode of transmitting motion is resorted to only when a small force is required, such, for instance, as that needed to work the slide-valve of steam-engines.

Parallel Motion.—The beam and counter-beam is an arrangement for ensuring the rectilineal motion of a rod. To the end of a beam O A, Fig. 2371, which turns about a horizontal axis in the point O, are jointed, on both sides, two equal rods having as their common projection on the figure the straight line A B. The ends of these rods corresponding to the point B, are jointed to two other equal rods projected in B C, turning about a horizontal axis in C, and forming what is called the *counter-beam*. In the middle M of the two former rods is fixed a horizontal axis, to which is jointed the end of the rod whose motion is to be in a straight line. To form an accurate idea of the motion which the axis M may assume, it will, evidently, be sufficient to consider the locus described by a determinate point M in a moving straight line A B, resting at its ends upon two circumferences, the centres of which are O and C, and the radii O A and C B. This locus is the Lemniscate. It has the form of the digit 8 much extended vertically, the multiple point of which

is situate upon the straight line joining the centres O and C. The tangent is, in this point, sensibly confounded with the curve throughout a long distance, a circumstance that enables us to consider, within certain limits, the point M as describing a straight line; we shall see later that the error in this way committed is practically quite inappreciable. The long-inflexion curve may be easily constructed by points; for, if we assume the beam to be in any position A O, the point B may be found by the intersection of two arcs of circles described from the points A and O as centres with radii equal respectively to the length of the connecting-rod, and to that of the counter-beam. Having found the position of the connecting-rod, we have only to mark on it the point M, whose distance from the point A is known. It is also easy to construct the tangent to the point M; for if we produce the radius O B till it meet the radius O A in I, the point I is the *instantaneous centre* of the motion of the connecting-rod (see M. Chasle's theorem of instantaneous motion); consequently, by joining M I, we get the normal in M to the curve described, and a perpendicular drawn through the point M gives the tangent. Many mathematicians have endeavoured to find the equation of the long-inflexion curve; M. de Prony, in an article inserted in the Annales des Mines in 1826, and M. Vincent, in an article contributed in 1837 to the Transactions of the Society de Lille, considered the question in an especial manner.

Belanger's method of calculating the co-ordinates from the point M for a given position of the beam, does not lead to some practical results. Thus let O X and O Y be two axes, one horizontal the other vertical, passing through the point O; let M D and O D be the co-ordinates y and x of the point M with respect to these axes, and let O A = R, C B = r, A B = l, A M = λ, A O X = α. Draw A H parallel to O X, A a and C P parallel to O Y. We have immediately

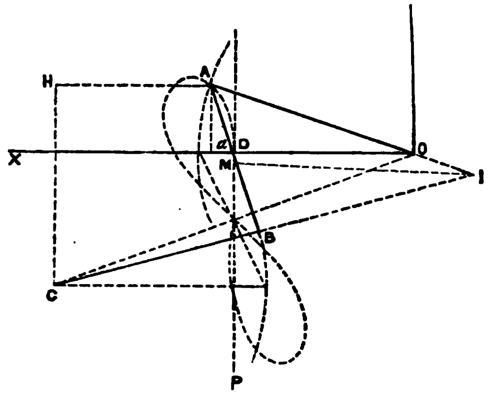
$$O a = R \cos. \alpha \text{ and } A a = R \sin. \alpha.$$

Hence we deduce the distances C H and A H, and consequently the hypothenuse A C of the rectangular triangle A H C, and the acute angle C A H. In the triangle A B C, therefore, we know the three sides, and the angle C A B may be found by the usual methods. The sum of the angles C A H and C A B is thus determined, it is the angle of A B with the axis O X. Representing this angle by β, we obtain, by the fundamental property of projections,

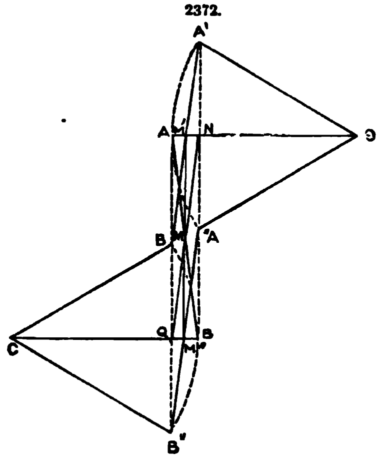
$$x = R \cos. \alpha + \lambda \cos. \beta, \text{ and } y = R \sin. \alpha - \lambda \sin. \beta.$$

This calculation is necessary to ascertain the deviation between the curve and the tangent to the multiple point, which a diagram even if constructed on a large scale could not make apparent. We thus see that, above the multiple point, the curve deviates to the right of the tangent at first and then approaches it, cutting it finally to form the upper loop. In the same way, below the multiple point, the curve deviates to the left of the tangent, then approaches it and crosses to the right to form the lower loop.

2371.



2372.



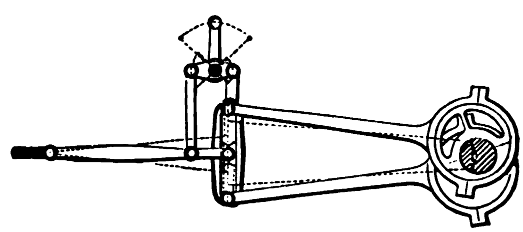
Usually the beam and the counter-beam are made equal, and they are arranged in the following manner, according to the rules laid down by Watt. Let O A, Fig. 2372, represent the horizontal position of the beam, and O A′, O A″ the extreme and symmetrical positions assumed by it in its alternating motion. The angle A O A′ is made equal to twice the angle, having as its tangents $\frac{1}{6}$; hence we conclude that the value of the sine of A O A′ is $\frac{12}{37}$, which determines the length O A of the beam when the length of the half-chord A′ N is known. It may be remarked in passing that the value of the angles A O A′ itself is 18° 55′ 28″. The counter-balance is so disposed that, in its horizontal position, its extremity B may be upon the chord A′ A″ produced, and as the excursions of the counter-beam are here equal to that of the beam, it follows that the point B is in its turn upon the chord produced B′ B″ which joins the extreme points of the arc described by the end of the counter-balance. The point M being in the middle of the connecting-rod, it follows that the point M, corresponding to the mean positions A′ B′ and A″ B″, are in the same straight line parallel to the chord A′ A″, dividing A N into two equal parts. A′ A″ and B′ B″ being equal and parallel, the figure A′ B′ B″ A is a parallelogram; the straight line M′ M″ joining the middles of the sides A′ B′ and A″ B″ is, therefore, parallel to A′ A″. Again, the figure A N B Q

is a rectangle; and M'M" is confounded with one of its middle lines, since it is at an equal distance from A' B and A B"; therefore, the middle M of the diagonal A B is upon M M". Finally the point M is also the middle of the diagonal N Q, which is one of the middle lines of the parallelogram A' B' B" A"; therefore, the point M is the middle of M' M"; and this straight line is equal to A' A" or to B' B". But M' M" is the stroke or travel of the rod to be guided; the chord A' A" should, therefore, be taken equal to this stroke. In this diagram the length A B of the connecting-rod has been taken arbitrarily; but Watt recommends the adoption of a length equal to the chord A' A", or at least to the $\frac{4}{5}$ of this chord.

The lemniscate, which in the present case takes more particularly the name of Watt's curve, passes, as we have seen, to the right of M M', and returns in M', passing thence to the left; but the calculation shows that the greatest deviation between the curve and M M', which happens at about $\frac{5}{8}$ of this distance reckoning from M, does not reach 0·0003 of the radius O A; the same deviation occurs on the left of M". This deviation, it will be perceived, is altogether imperceptible. M. Tchebycheff, in a learned communication to the Mémoires de l'Académie de Saint-Pétersbourg, has demonstrated that the proportions adopted by Watt are not those which correspond to the minimum of deviation; but they have been generally adopted on account of their simplicity. It has also been shown that the deviation may be diminished by making the chord A' A" greater than the stroke of the rod to be guided, because in that case the joint of the rod would not reach in its motion the positions corresponding to the maximum of deviation. But this would cause another objectionable feature, namely, a useless increase of the dimensions and weight of the beam.

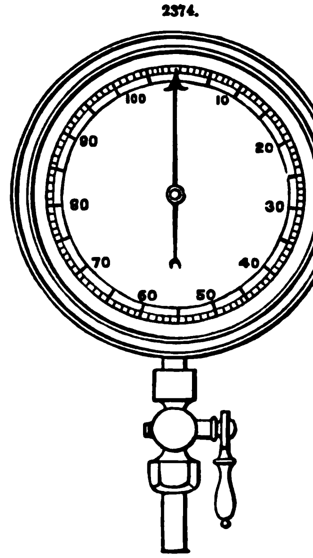
Straight-Link Valve-Motion, Fig. 2373.—By this arrangement, invented by A. Allen, simultaneous movement is given to the eccentric rods and link and to the valve-rod, in opposite directions, by short levers placed on opposite sides of the reversing shaft, thereby obtaining a straight link. This valve-motion is easy of reversal, balance weights are dispensed with, and the sliding movement of the block is reduced. The only fixings required are the reversing-shaft brackets. Most accurate results as regards an equal distribution of the steam can be obtained by this motion; while from the simplicity of the motion and from the link being straight, in place of curved, repairs are more economically executed.

2373.



Pressure Steam-Gauge, Foster's Direct-acting.—With respect to accuracy, durability, mechanical arrangement, and efficiency, no spring steam-gauge that has fallen under our notice, and we have examined many, equals that of Foster, Figs. 2374 to 2376.

2374.



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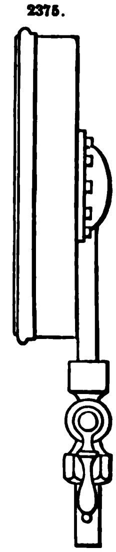

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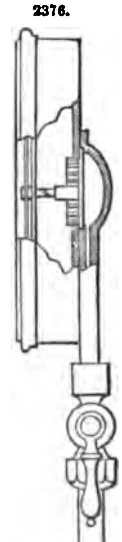
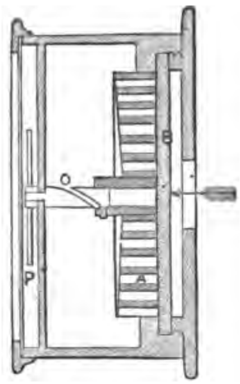


In Fig. 2376 the cover is removed to show the position of the spring, the spindle and its screw-shaped slot. The coiled flat spring of this gauge is shown in plan Fig. 2378, of which A, Fig. 2377, is a section. Figs. 2379, 2380, are of one of Foster's testing gauges, full size; this small gauge can be made to indicate up to 300 lbs. without increase of size. A plate of vulcanized rubber B, Fig. 2377, rests upon the spring. O, Fig. 2377, spindle with screw-shaped slot; one end of this spindle rests in a socket-piece fixed in the centre of the spring A; the other end has the

index hand P fixed to it. The means employed to communicate a rotary motion to the spindle is by a small pin fixed in the socket-piece at right angles, which obtrudes into the slot O, Fig. 2377. Now as the pressure on the plate of rubber deflects the spring, the pin slides up the slot and

2377.



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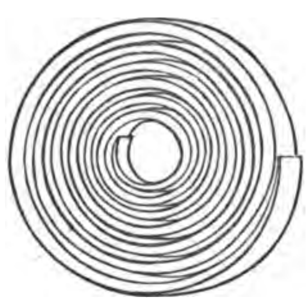

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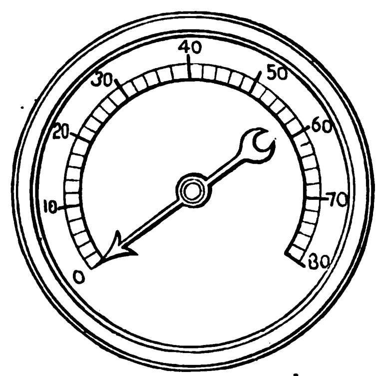

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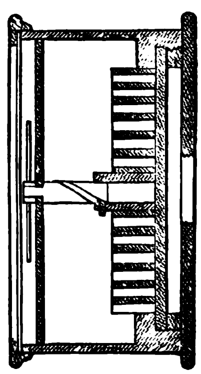

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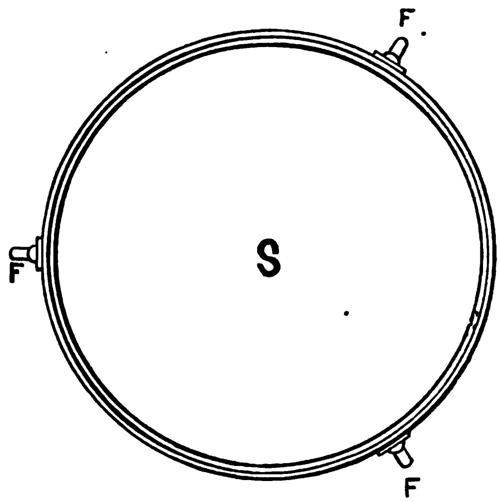
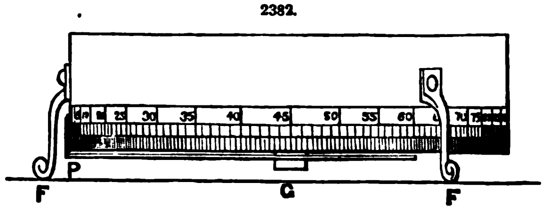


causes the spindle with the index to revolve; the reverse action taking place when the pressure is being removed. These gauges of Foster and Barnett are extremely simple in construction; there is nothing to get out of order, the spindle which carries the hand has only its own weight to support;—they are very sensitive, as the slightest pressure is immediately shown by the hand. Foster and Barnett carry out the same principle in weighing machines, which shows that the action of a spring so formed is uniform. One of those weighing machines is shown in Figs. 2381 to 2383. Fig. 2381 is a plan, Fig. 2382 an elevation, and Fig. 2383 a section. F, F, F, feet or supports. C P, Fig. 2382, the pointer. S the scale or disk of balance. The slot, of which we have before spoken, is well defined in Fig. 2383.

2382.



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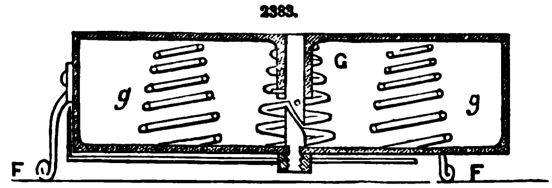
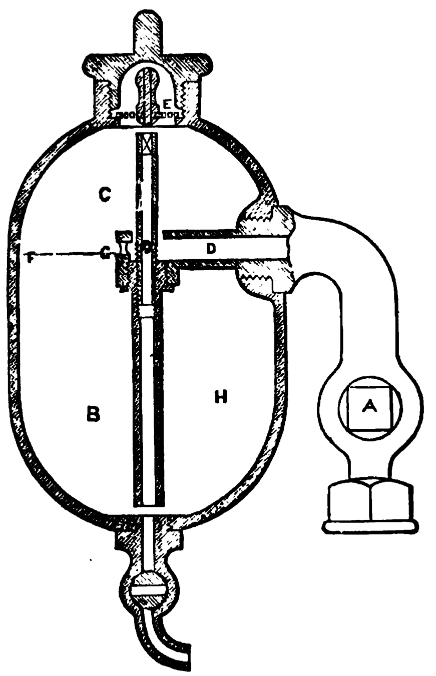


Lubrication of Steam.—It has been found advisable and generally necessary to grease the interior of the steam-cylinder; sometimes the slide-valve. If the steam is very wet, the attraction of the walls of the cylinder causes a certain quantity of water to be deposited on them, and the friction is not excessive enough to cause the engine to groan, hence engines are occasionally met with in which, because of the wetness of the steam used, there are no special means of lubricating

the internal rubbing parts of the steam-cylinder. But it has been found more economical to have the steam superheated or at least somewhat dry; it then appears more or less blue when let off into the open air. It is for such cases that special means of lubrication are necessary. The prevailing method is the *grease-cock* on the steam-cylinder, and sometimes a smaller cock on the slide-chest. The grease-cock is in the shape of a hollow ball with a cock above and another below. A cup of the same capacity as the ball surmounts the upper cock. The latter being closed, the cup is filled with grease, generally tallow, the lower cock shut and the upper opened, when the cup will empty its contents into the ball, and by then closing the upper and opening the lower cock the tallow is drawn into the cylinder. It is singular that such a rough contrivance is still extensively used, while shafting is generally lubricated by some sort of self-acting means, such as capillary attraction in a wick, or by the needle lubricator. No sensible person would say that he preferred to empty the contents of the oil-cup into the bearing at once, and yet engineers do a similar action when they use the old grease-cock on the cylinder.

Of late years the subject has been agitated considerably, and locomotives for instance are now seldom seen without some self-acting means for greasing the steam continuously before entering the slide-valves. Also among stationary and marine engines the principle is being successfully applied. By lubricating steam not only is the friction of piston, slide-valve, piston-rod, and slide-rod reduced to a minimum, which means a saving in fuel, but there is also great saving of tallow and oil. Among the best known and approved lubricators may be named those invented by Roscoe, Wilson, Ramsbottom, Clements, and Gamble. The last named, of which Fig. 2384 is a section, is perhaps the simplest and most practical of them all. Supposing it to be connected to some part of the steam-pipe close to the slide-chest; the steam, entering through the cocks A, passes through D into the lubricator, which is filled with tallow B, H, up to the level F, G, of the steam-pipe, and stands over the surface of the tallow at C. The steam condenses, and, water being heavier than tallow, falls to the bottom, thereby displacing a certain quantity of tallow which is thus forced over into the steam-pipe in a constant, slow, and dribbling stream. To meet the various requirements of the various engines and the various temperatures the lubricators are placed in, which of course produce quicker or slower condensation of the steam in the lubricator and consequent quicker or slower feed of tallow into the steam, there is a simple and ingenious contrivance. It will be observed that the steam-pipe at its termination in the centre of the lubricator has a small hole at the tallow level, for the entrance of the fresh steam into the lubricator and the egress of the greased steam. The steam-pipe has a siphon-pipe screwed into the bottom, reaching nearly down to the inside bottom of the lubricator. Into the inside top of the siphon-pipe is screwed the small regulating pipe, which has a small hole in its side, and has plenty of play round it where it passes through the steam-pipe. If this pipe is screwed down so as to have the hole in its side below the steam or tallow hole, then, owing to capillary attraction, the water will take the preference, and will continue to be siphoned out from the bottom as fast as it comes in and condenses, so that little or no lubrication takes place. On the other hand, if the regulating pipe is screwed up so that its hole comes somewhat over the tallow hole, then no water will be siphoned out from the bottom, and a very plentiful lubrication takes place. In any intermediate position, partly water and partly tallow will overflow into the steam-pipe; the proportions can be regulated to the greatest nicety. A strainer E is fixed over the filling hole, so as to clear the tallow if it should be dirty. See AIR-PUMP. BOILERS. BUFFER. ENGINES, *Varieties of*. FUEL. GEARING. INDICATOR. LINK-MOTION. LOCOMOTIVES. MARINE ENGINE. MECHANICAL MOVEMENTS. PARALLEL MOTIONS. PUMPS AND PUMPING ENGINES. SLIDE-VALVES. SPRINGS. STATIONARY ENGINES. STEAM AND STEAM-ENGINE.

2384.



DEVIL. FR., *Loup; Machine à ouvrir;* GER., *Wollbrecher; Wolf;* ITAL., *Diavolo.*

Devil is a rude term applied to a machine containing a revolving cylinder armed with spikes or knives, for tearing, cutting, or opening raw materials, as cotton, wool, rags.

DIAL. FR., *Dyal;* GER., *Zifferblatt;* ITAL., *Orologio solare;* SPAN., *Reloj de sol.*

A *dial* is an instrument for showing the apparent time of day from the shadow of a style or gnomon on a graduated arc or surface. When the shadow is cast by the sun, it is also called a *sun-dial.*

The term *dial* is applied to the graduated face of a time-piece on which the time of day is shown by pointers. A miner's compass is also termed a *dial.* See COMPASSES, p. 1015.

DIES. FR., *Matrice;* GER., *Matrize;* ITAL., *Matrice;* SPAN., *Cuño, Matriz.*

See HAND-TOOLS, *Stocks and Dies.*

DIGESTER. FR., *Marmite;* GER., *Kalcinirtopf;* ITAL., *Digestore;* SPAN., *Marmita.*

A digester is a strong closed vessel, in which bones or other substances may be subjected, usually in water or other liquid, to a temperature above that of boiling.

DISPLACEMENT. FR., *Déplacement;* GER., *Versetzung;* ITAL., *Spostamento, Portata;* SPAN., *Líquido desalojado.*

Displacement.—Bodies, says J. Scott Russell, which are designed to float in water, must be so designed, that when they are put into the water sufficiently far to swim just so much out of the water as is intended, the part in the water shall be of the exact size necessary to displace the quantity of water intended, and that the body which floats shall be of the exact weight of the water it displaces.

Let us see what will happen if this be not accurately done. Suppose the bulk of the body has been made too small for the weight which it is intended to carry, the vessel will sink deeper into the water than had been intended; and by sinking so much it will displace the additional quantity of water necessary to make up the extra weight, and so, though it swims, it will swim too deep. More displacement must therefore be found to meet the deficient weight; the vessel, which was intended to swim light, will swim deep in the water, unless her weight be diminished by lightening until she return to her intended former depth. What is to be taken care of in the calculation, therefore, is, that at whatever depth it has been decided that the ship shall float in the water,—or, which is the same thing, at whatever height the upper part is to float above the water,—in that position the bulk of the part in the water, and the weight of the whole ship and its contents, must be so designed as to be exactly equal to the bulk of the water to be displaced by the ship, and the weight of the water to be so displaced.

In a ship it is necessary to do more, however, than calculate one displacement. There are two critically important displacements to be calculated for every vessel—displacement when she is lying in the water ready to take in her cargo, or in the lightest state in which she will ever swim, that is, with a clean-swept hold; this is technically called light-displacement. The other is load-displacement, which is calculated for the heaviest cargo she will ever carry, and the deepest draught of water to which she will ever sink under load. These are the two critical draughts of water, or depths of the ship in water.

To calculate these, the constructor must first ascertain the exact weight of the hull of the ship. He must include in the weight of the hull all the essential parts attached to, and connected with, that hull. He must add to that the full equipment necessary to fit her for sea-going use; but he must not include those stores—water, provisions, coals, and so on—which are to be consumed in actual service. This weight of hull and equipment for service constitute the data on which to construct the light-displacement of the ship.

The load-displacement is next to be calculated. The data for this consist, firstly, of the light-displacement, and secondly, in addition to this, of all the stores, provisions, water, coals, and consumable commodities to be used on the particular voyage intended, together with the cargo or freight of every kind which has to come on board.

To the light-displacement corresponds what is called the light-draught of the ship, and to the load-displacement the load-draught. There is also the light-trim of the ship, and the load-trim of the ship. In some foreign tongues draught is called *deep-going* of the ship, and this phrase gives the exact meaning of draught. Trim means difference of draught, or rather the difference between the depth of the after part of the ship under water and that of the fore part.

It is usual to give a ship such trim that the draught of water abaft is somewhat deeper than the draught forward. In this case she is said to be trimmed by the stern. If it were the contrary, she would be said to be trimmed by the head. This is what is meant when it is said that a ship is trimmed 2 ft. by the stern, or 2 ft. by the head, this difference of 2 ft. either way being technically called the trim. When a vessel is trimmed neither by the head nor by the stern, but draws the same water forward and aft, she is technically said to be on even keel. It is usual to take a middle draught, half-way between the fore and after draughts, and to call that the mean draught of the ship; so that a ship which is trimmed to 21 ft. at the stern and 19 ft. at the bow, is said to have a mean draught of 20 ft. In this case it is common also to call this the draught of water of the ship, and to call the greatest draught of water, whether at the stern or bow, the extreme draught. In calculations of displacement we generally use the mean draught.

The elements to be considered in calculating displacement are as follow;—

1. Dead-weight when light.
2. Dead-weight when laden.
3. Light-draught of water.
4. Light-trim.
5. Load-draught of water.
6. Load-trim.

These elements settled, we can now calculate exactly the displacement of a ship of any given form, of which we may possess a design—firstly, for her light-draught of water; secondly, for her load-draught.

First, for her light-draught, we mark off on the drawing of the ship the exact part of the body of the vessel which will be under water when she floats light. We call this the immersed body of the vessel (light). We then measure exactly, and calculate geometrically, the bulk of this immersed body. This bulk will be expressed in so many cubic feet—say 18,000. We next take the weight given for the ship and her equipments when light—say 500 tons.

Now we know that a ship will float at a given draught of water when the quantity of water she displaces is of exactly the same weight as herself. In this case her weight is given as 500 tons. The question, therefore, is, Whether the volume of water, namely, 18,000 ft.—which is the bulk of the immersed body, and which is, therefore, the quantity of water displaced—will weigh more or less than 500 tons?

Now it will be found that the bulk of 500 tons of water is just 18,000 cub. ft., and the displace-

ment of the ship, as measured, is also 18,000 cub. ft.; this, therefore, is the true light-displacement.

Secondly, for her load-draught, we mark off on the drawing of the ship the exact part of the body of the vessel that will be under water when she is deep laden. We then measure exactly, and calculate geometrically, the bulk of that part of the vessel which was formerly out of the water, but which has now been sunk under it by the lading. This bulk is, we will say, 36,000 cub. ft. Thirty-six thousand cub. ft. of water weigh 1000 tons; therefore 1000 tons is the dead-weight of cargo which the vessel will carry on the given load water-line.

But the total load-displacement of the ship consists, first, of the light-displacement of 18,000 cub. ft.; second, of the lading-displacement of 36,000 cub. ft. more; so that the total displacement of the ship, when laden, is the sum of the two, or 54,000 cub. ft. The immersed body of the ship at the load-draught has therefore a total displacement of 54,000 cub. ft.; and the ship, with her cargo, floats a total weight of 1500 tons.

It is thus that the simple law of Archimedes reduces the question of calculating the weight a ship will carry at a given draught of water, to a mere question of measurement of the bulk of that part of the ship which will then be under the water, and which we have called the immersed body. For every cubic foot of that immersion we allow the weight of that cubic foot of water, and thence obtain the number of tons weight the water will support. This is said to represent the floating power of the ship; it really represents the buoyant power of the water acting on the outside of the ship. The ship itself has no power to carry anything or to float; all it does is to exclude the water and enclose the cargo. The ship is merely passive—the water carries both the ship and her cargo. Buoyancy is, therefore, the power of the water to carry a given ship. It is proportioned exactly to the bulk of the body of the ship under water, and its force is measured by the weight of the water displaced, and which we have called the *ship's displacement*.

There is an important conclusion to be drawn from this law, and it is, that the floating power of a ship has nothing to do with the shape of the ship, but is entirely due to its size or bulk. Practical ship-builders, ignorant of the laws of naval architecture, have imagined that they could confer surprising powers of flotation, and ability to carry heavy weights, merely by giving proper shapes, imagined by themselves, to the immersed bodies of their ships. Some of them, of considerable eminence, have been known to pass a long period of their lives under this delusion, and a very distinguished one even wrote a treatise on the subject; but the delusion passed away, and the authority of Archimedes was re-established. The fact, however, of the existence and practical application of the opposite opinion tends to show that the principle of flotation is by no means self-evident, and the discovery of Archimedes had great merit. Its practical value to us is its admirable simplicity, its unquestionable authority, and its absolute exactness. To understand its nature is, however, less easy than to appreciate its value; and it will take a great deal of thought to understand thoroughly, why no possible invention of shape can give to a ship the power of greater or less buoyancy, than is measured by the exact weight of water which forms its displacement.

STANDARDS OF DISPLACEMENT.

Weights.		Bulks.		Sizes.	
*1	ton	*36	cubic feet fresh water	2 × 3 × 6	feet
†1	"	†35	" sea water	2 × 2·5 × 7	"
*62·5	pounds	*1	" fresh water	1 × 1 × 1	"
†64	"	*1	" sea water	1 × 1 × 1	"
10	"	1	gallon fresh water ‡	6 × 6 × 7·69	inches
1	"	27·648	cub. in.‡ "	3 × 1 × 9·216	"
1	ounce	1·728	" "	1 × 1 × 1·728	"
0·58	"	1	" "	1 × 1 × 1	"
2	tons	72	cubic feet	6 × 6 × 2	feet
3	"	108	"	6 × 6 × 3	"
4	"	144	"	6 × 6 × 4	"
5	"	180	"	6 × 6 × 5	"
6	"	216	"	6 × 6 × 6	"
10	"	360	"	6 × 6 × 10	"
100	"	3,600	"	6 × 12 × 50	"
200	"	7,200	"	6 × 12 × 100	"
300	"	10,800	"	6 × 12 × 150	"
400	"	14,400	"	6 × 12 × 200	"
1,000	"	36,000	"	12 × 24 × 125	"
10,000	"	360,000	"	24 × 50 × 300	"
20,000	"	720,000	"	24 × 75 × 400	"
30,000	"	1,080,000	"	24 × 75 × 600	"

* 62·5 pounds $= \frac{1}{35\cdot84}$ tons $= \frac{1}{36}$ tons nearly, and 1 ton = 35·84 ft. distilled water.

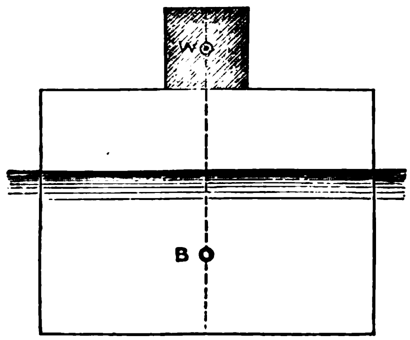
† 64 pounds $= \frac{1}{35}$ tons exactly, and 1 ton = 36 ft. salt water.

‡ The imperial gallon is defined by the Act of 5 Geo. IV., c. 74, as containing 10 pounds of distilled water, at a temperature of 62°·5 Fahr., and also as measuring 277·274 cub. in. If we take ordinary fresh water at a lower temperature (40° Fahr.) as our standard, a cubic foot of fresh water will weigh *exactly* 1000 ounces, or 62·5 pounds. All the figures given above are correct within a very small fraction. 36 cub. ft. of fresh water and 35 cub. ft. of salt water are the practical numbers usually taken to measure 1 ton of displacement.

Simple form of Vessel, as an Experimental Shape, is a Box.—To understand the functions of the shoulder of a ship, and those of the bottom, and the tendency of both to effect the stability of the ship, it will not be necessary to consider any but the simplest form which can float. Let us take for that purpose a square box of large size, say 36 ft. wide, 27 ft. high, and of indefinite length, and let us sink it by a weight to 18 ft. deep in the water. Each foot long of a box having this breadth and height will carry a ton weight, for every foot of its depth in fresh water. Being 36 ft. wide, a foot in depth displaces 36 ft. of water, the weight of which is 1 ton; therefore, 18 ft. deep will weigh 18 tons: and suppose the box itself to weigh 6 tons to a foot forward, the vessel would carry besides itself a weight of 12 tons. Let us draw in the figure such a box, and across it the line of the surface of the water, which we shall call always the water-line. Let the weight on the box be also a box, filled with heavy lead or iron, represented in Fig. 2385 as placed on the top of it.

This box truly represents a ship, the weight truly representing a heavy deck-load, proposed to be carried by the ship. It may represent the weight of an armament of artillery, or the weight of an iron-coated battery, or any other top-load

2385.



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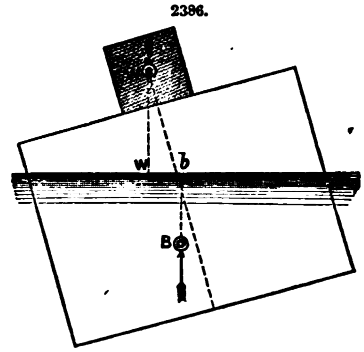

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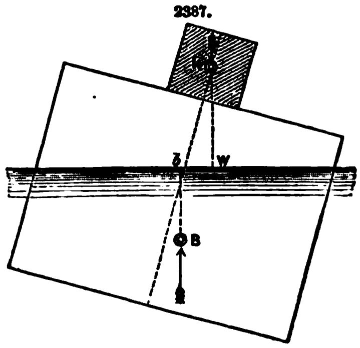

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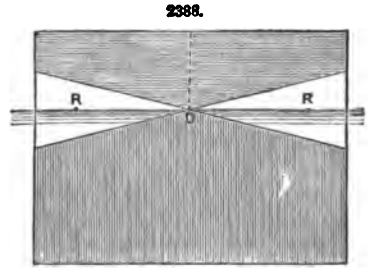


The question is, the ability or inability of that ship to carry that weight at that height out of the water. For this purpose we must conceive it to lean over on either side, and then examine whether it tends to return to the upright position and stand up, or to overset and let the weight into the sea. Let us, therefore, draw the ship in these two positions, Figs. 2386 to 2388. When we have done this we shall see that there is a part of a ship which is never out of the water, but keeps always under the water-line. Let us shade this part differently from the other. It is called the under-water body of the ship, and it is also called the upsetting part of the ship. This under-water body is bounded by, first of all, the bottom of the ship; secondly, by the bilges, or corners of the bottom; and thirdly, by a water-line of the ship in each of its two opposite positions. It is, therefore, pointed at the top, where it forms an equal-sided triangle, the apex of which is in the water-line. Two flat surfaces, therefore, form the top of this under-water body, and the rest of it form the bilges and bottom, or under-water skin of the ship. It is this shaded part whose action is to upset the ship.

Let us now examine the nature of the upsetting force produced by the under-water body, Figs. 2389, 2390. For this purpose, I observe that it is a symmetrical body, the right and left sides being of the same size, of the same shape, and in the original upright position of the body exactly balancing each other on both sides.

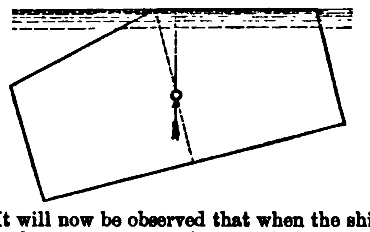
We may, therefore, take its whole effect as concentrated in a point in its middle line. This point we shall call B, or centre of effort of the under-water body.

The buoyancy or upward pressure of this under-water body will take place directly upwards in the line B *b*, and it will be noticed that it is quite on one side of the centre of the vessel. It is next to be noticed, in Figs. 2386, 2387, that the centre of the weight W is on the opposite side of the upright line. When the ship careens over to the right, the weight also inclines to the right,

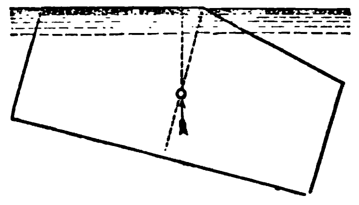
and downwards; when the ship careens over to the left, the weight also inclines to the left, and downwards.

We have marked the direction of its effect by the line downwards from W.

2389.



2390.



It will now be observed that when the ship is lowered on the right side, the effect of the weight from above is to press it downwards on that side. Unluckily, at the same moment the effect of the under-water body is equally bad, raising the opposite side out of the water. The ship is beset by two opposite forces, which, nevertheless, conspire in their bad effect: one sinks the right in the water, while the other lifts the left out of the water, so that with opposite means both overset the ship.

Stability.—The substance and sum of what we know of the nature of stability is this;—the shoulders alone give to the ship righting or uprighting power. No other part of the ship can be so formed as to increase the righting power given by the shoulders. The righting power given by the shoulders is equally effective in squaring the ship to the water, whether it be still water or wave water.

The bottom of the ship, or the under-water body, can in no way help the ship to keep upright; there is no kind of bottom on which the ship can be said to rest in the water; the most that any underbody can do, either by shape or size, is to take less away from the stability given to the ship by the shoulders, than some other shape or size of underbody takes away. Size of bottom, therefore, or quantity of under-water body, lessens the stability of a ship; and has to be counteracted by the power of the shoulders. In short, bottom upsets the ship; so much so, indeed, that if it be large and powerful, it may take more than the whole power of the shoulders to keep it down, and prevent the ship from capsizing. A large underbody, therefore, weakens the effect of the shoulder, by the whole of its upsetting power.

It is only, therefore, the surplus power of the shoulder remaining over and beyond what is employed to keep down the underbody, which we are able to make use of in carrying press of sail, or in supporting top-weight out of the water. If there be any such surplus, it is our business to find out how much that is; if it be enough to carry press of sail, and enough also to carry top-weight, then the ship may be able to do without ballast.

Ballast, in the general sense of the word, signifies weights carried under the water, as distinguished from weights carried above the water, or top-weight. There are two ways of ballasting a ship; one is, by real lading, or stowing heavy weights under the water; the other is by putting weights, which are not parts of the lading, nor essential parts of the ship, low down in the water, for the mere purpose of helping the shoulders to carry top-weight. Weight placed under the water, in either way, may be said to have the following effects;—First, by being under the water as far as the top-weights are above it, it neutralizes the bad effects of these top-weights, and balances them. In this way under-water weight helps the shoulders to carry top-weight.

There is another way of looking at the effect of under-water weight in giving stability; it aids the shoulders in keeping down the underbody. In this way, as well as in counterbalancing top-weight, under-water weight helps the shoulders.

Thus it is that there come to be three agents in stability; two arising from shape alone, and one from disposition of weights. The shape and size of shoulder give stability of form. The shape and size of underbody give instability of form. What of the power of the shoulder remains beyond counteracting this underbody is the true surplus stability, or measure of righting power, for that form. This surplus is all that can be used for navigating a ship and carrying her top-weights. If more stability be wanted, it can be obtained by weight alone. All the weights of a ship, which have their common centre of gravity in the middle of the ship, just between the two shoulders, neither help the stability nor hinder it. Only weight placed below the middle of the shoulders gives help, and increases stability; and if the centre of all the weights of ship, cargo, and ballast, taken together, fall above the water-line, the surplus power of the shoulders may enable her to carry sail. If not, there is no resource left but to lower the weights in her, or place ballast in her bottom; in other words, to supply the defect of stability of form by adding stability of weight.

As, therefore, stability of form is that power which the naval architect alone can confer on his ship; while stability of weight may afterwards be regulated by those who lade, and control, and navigate the vessel; the form and action of the shoulders are the province in which the skill, contrivance, and forethought of the designer can be most powerfully and usefully employed. We shall, therefore, proceed to a general examination of the powers and properties of shoulders. We may take shoulders as meaning those portions of a ship which, in heeling contrary ways, rise out of, and sink into, the water; or the parts of the ship between wind and water; what is below the shoulders being bottom, or under-water body; the remainder, above the water, being called top-sides.

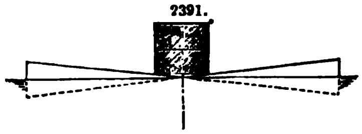
Power of Shoulders to carry Shifting Weight.—The power of the shoulders of a ship is shown when heavy weights, which tend to overturn the ship, are sustained above the level of the water;

also, when they enable a ship to support heavy weights shifted out of the centre towards either side; also when they enable the ship to stand up under press of sail. This being the nature of the work the shoulders have to perform, in order to prevent the oversetting of the ship, the manner in which they accomplish the work is as follows;—One shoulder sinks deeper into the water, the other rises out. The effect is, that the shoulder in the water is increased in power by the quantity which falls into the water; and the other is diminished in power. Thus, the burden which one shoulder can carry becomes greater than the other; and the question arises, whether it thus becomes great enough to bear the additional force thrown on that side of the ship, or whether the force is too great and overturns it.

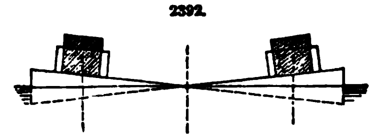
The question, how much the power of a shoulder is increased by its depression under water, depends on its size and shape, and on the place of its action. If the two shoulders are equal, and equally immersed and vertical at the sides, then the whole weight carried by both shoulders may be shifted to one side of the ship, to the extent of nearly $\frac{1}{3}$ of the breadth of shoulder, without overturning.

This may be well understood by studying the engravings which illustrate stability. Figs. 2391 to 2396 show a pair of shoulders carrying weight out of water. First, the whole is shown supported

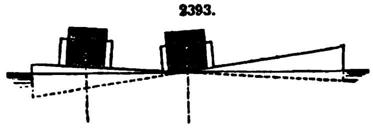
2391.



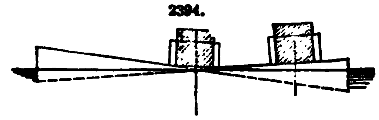
2392.



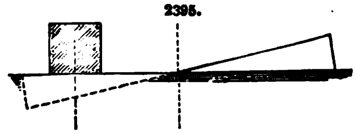
2393.



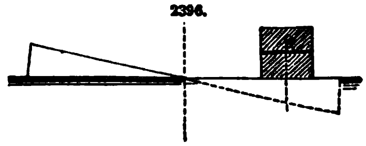
2394.



2395.



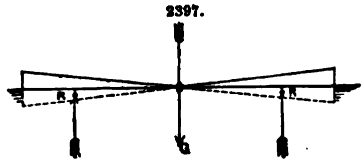
2396.



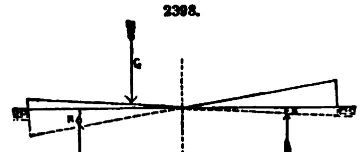
in the middle by the joint power of both shoulders; next, each shoulder is shown carrying its own weight $\frac{1}{3}$ from the outside, and supporting each its own half without help of the other; next, one shoulder carries all its own load and also half of the other's; finally, the whole weight is carried on a single shoulder, the other being entirely relieved.

Figs. 2397, 2398, show exactly how these forces of the shoulders act. The centre O is the turning-point of a lever; the points R and R are the centres of displacement of each shoulder.

2397.



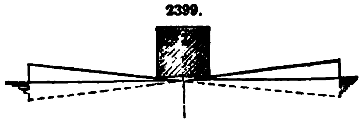
2398.



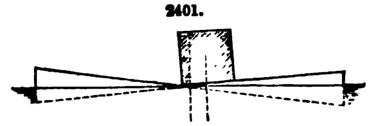
When they are equally in the water, their joint effect is on the middle; when unequal, their resultant effect moves over to the side of the more immersed shoulder.

Figs. 2399 to 2411 show the effects produced by the different immersions of one shoulder to equally increasing depths. With every increase of depth the centre of joint support shifts towards

2399.



2401.



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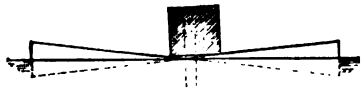

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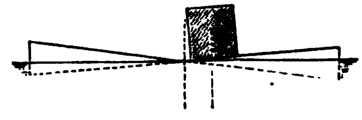

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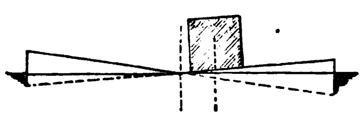
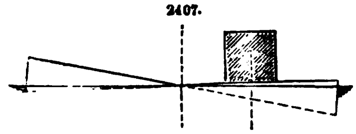
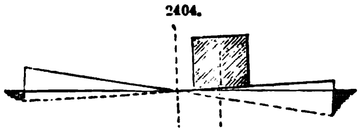


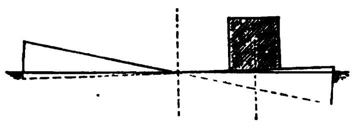
2407.



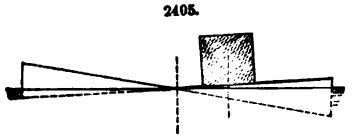
2404.



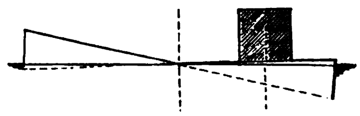
2408.



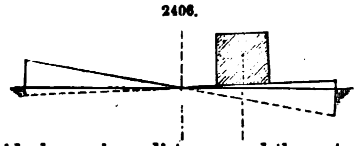
2405.



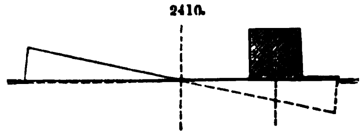
2409.



2406.



2410.



one side by a given distance, and the extreme shift is measured by the total immersion of one shoulder and total emergence of the other. With each immersion the total weight carried is shown on these figures at the point at which it is exactly balanced by the supporting forces.

2411.

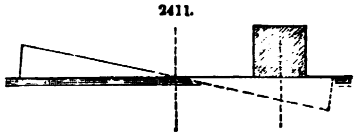
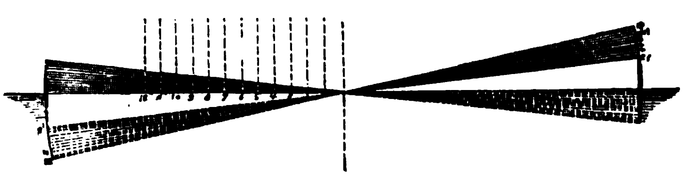


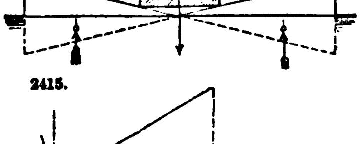
Fig. 2412 shows the manner in which the centre of power of the pair of shoulders shifts with the different immersions of shoulder; each successive centre of effect being marked 1, 2, 3, 4, 5, 6, and so on, for the corresponding successive depths of shoulder.

2412.

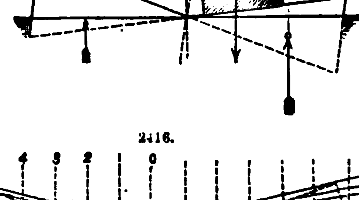


In the cases already examined, the depths of the shoulders are limited by angles of heel of 7° and 14° angle of shoulder. This is the standard angle for war vessels; but for merchant ships we use a heel of 14° 2′, or 28° 4′ for the angle of shoulder. This angle of shoulder is shown in Figs. 2413 to 2416, and the manner in which the centre of action of the pair of shoulders shifts

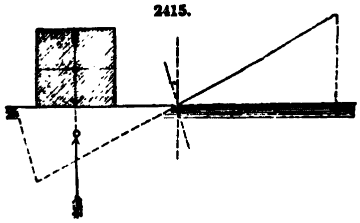
2413.



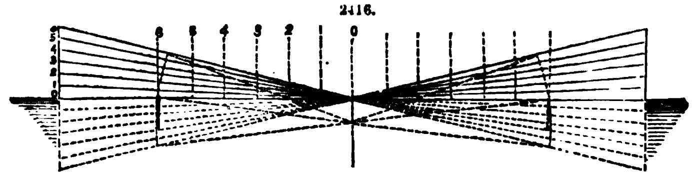
2414.



2415.



2416.

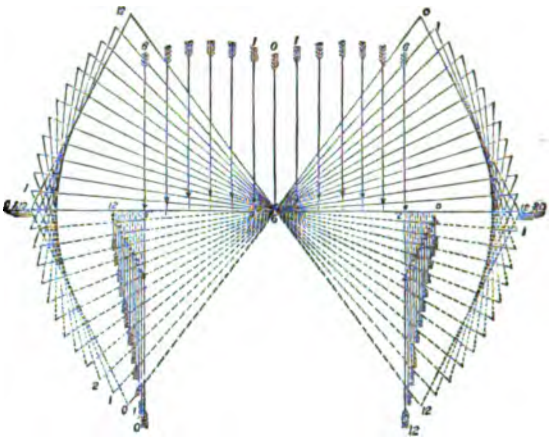


over to the sinking side is shown also. In Fig. 2416 the point under the centre of the shoulder is the centre of an arc, in which all the effective leverages of each shoulder lie.

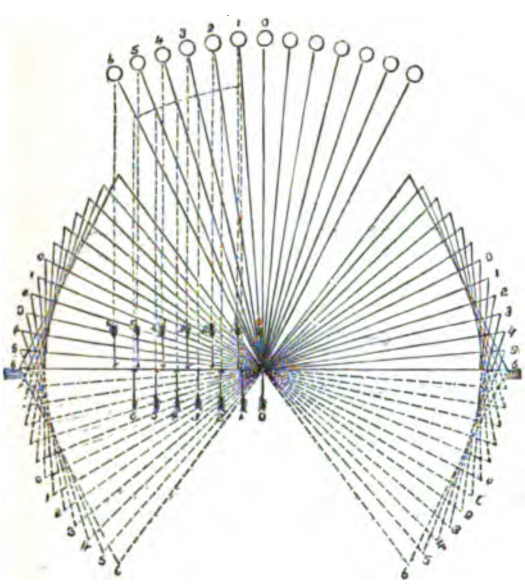
In Fig. 2417 the depth of shoulder is taken as extreme. The centres of action are shown in each shoulder, and the joint centres of the pair are also shown. It is worthy of notice, that while the sinking of one shoulder and rising of the other take place to uniform successive depths, the centre of joint effect shifts over also by nearly equal steps to the sinking side. Depth of shoulder, therefore, makes no material change in the law of shift of the centre of action of these shoulders. Each half-inch of dip of shoulder enables them to carry a corresponding shift of nearly one foot of weight.

On the Relations between the Shifting Power of Shoulder and the Shifting Place of fixed Top-Weight. — Hitherto we have shifted the weights across the shoulders, so as to place them directly over the points of joint action of the

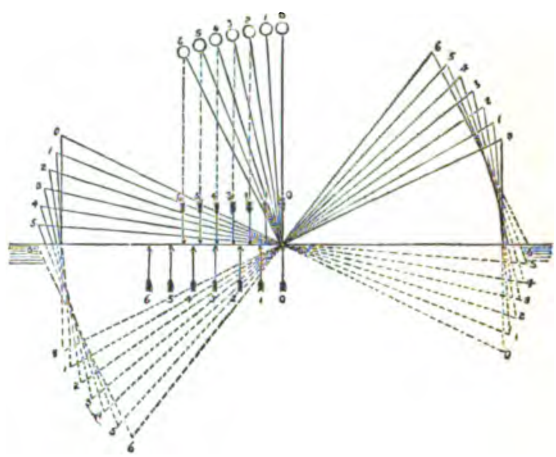
2417.



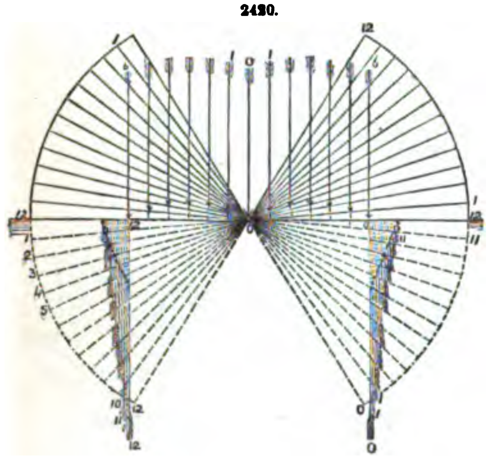
2418.



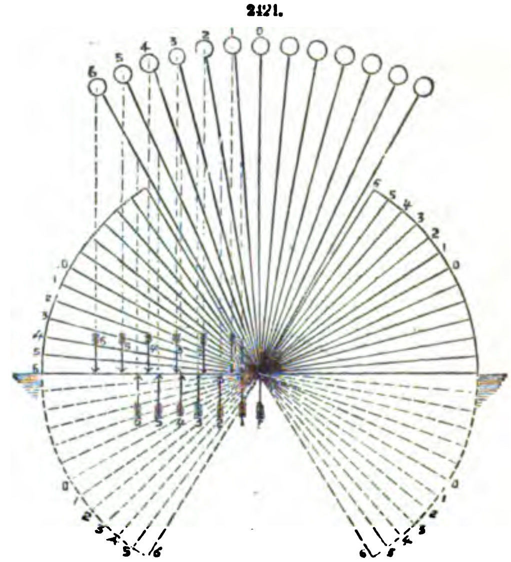
2419.



2420.



2421.



shoulders; and thus we have made an arrangement by which the weight and the shifting support exactly meet. But, in fact, the top-weight of a heeling ship follows a law of shift of its own, which is quite independent of the shift of shoulder. For each inch of heel of shoulder the fixed top-weight will incline over to the sinking side through the arc of a circle, and describe a given number of degrees; and it depends entirely on the height of the weight above the water what length the arc shall be, through which the weight will be shifted with that inclination. When the height is great, the arc large, the top-weight may travel faster than the point of support shifts, and upset; or it may travel slower, and stand. It depends entirely on whether the weight travels slower or quicker than the point of support shifts, whether the ship is stable or unstable.

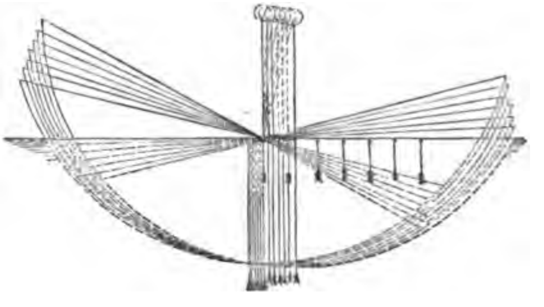
Figs. 2418, 2419, show these two cases. In the former the weight is high, and travels faster to the sinking side than the centre of support at the shoulders, and so would upset. In the latter, the centre of effort of the shoulders travels the faster, and gets always beyond the line of weight, so as to right the ship. It is also noticeable that, by lowering the weight in Fig. 2418 to a height shown by a dotted line, the shift of the weight might be diminished so as to become, at a certain point, exactly equal to the shift of centre of action of shoulder; and then the body would rest inclined exactly in that position. This dotted line, therefore, indicates the limit between stability and instability. It may be called the line of balanced stability.

Round Shoulders.—We have hitherto taken the shoulders, when upright, as having straight vertical sides, which is the common case of straight-sided ships. Fig. 2420 is the circular shoulder, and shows a similar equable shift of the centre of joint action of the shoulders with the heel of the ship. Fig. 2421 shows that the fixed top-weight shifts by a law which is not uniform. The shift of the centre of effort is uniform, and that of the weight is decreasing. The top-weight shifts faster than the centre of support. A dotted line shows where the top-weight should be placed, exactly to balance the support due to the position. The power of shoulder to carry weight depends, therefore, on this simple question, Whether the centre of joint effort shifts farther and faster than the centre of the top-weight travels in the same direction? and every case that can arise may be solved by the construction of a diagram similar to the figures we have engraved; or by a calculation founded on the same method.

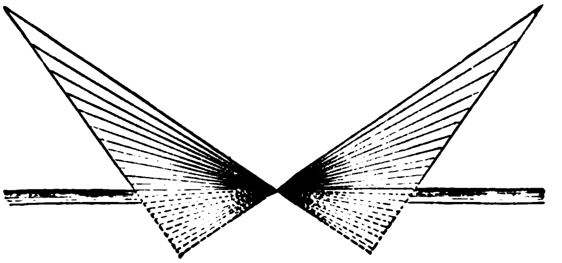
Inclined Shoulders show a very different law of stability from either straight or round shoulders. If we divide a pair of inclined shoulders by radial lines, cutting off equal parts of the inclined line above, we shall find that these lines cut the underwater part of the shoulders into unequal triangles. The out-of-water part of the shoulder being large, the under-water part is small.

This variable power of shoulder to carry weight with variable inclination, unfits it for the purpose of carrying a fixed heavy load with fixed stability. The diagrams show—1st, the constant weight carried by the equal shoulders as they incline; 2nd, the power given by the excess of shoulder on one side to carry increased weight; 3rd, the place where such increase of weight would be supported. The lengths of the arrows measure the forces they represent. See Figs. 2422 to 2427.

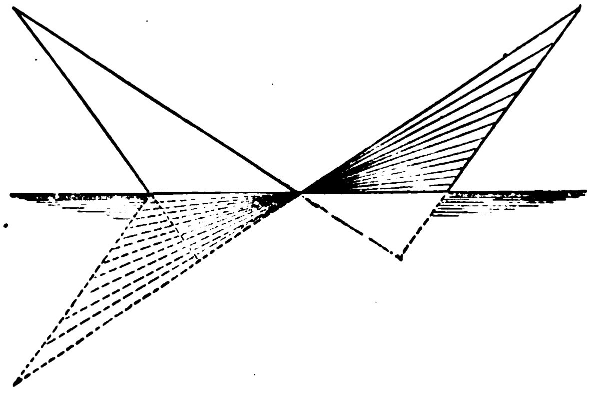
2422.



2423.



2424.



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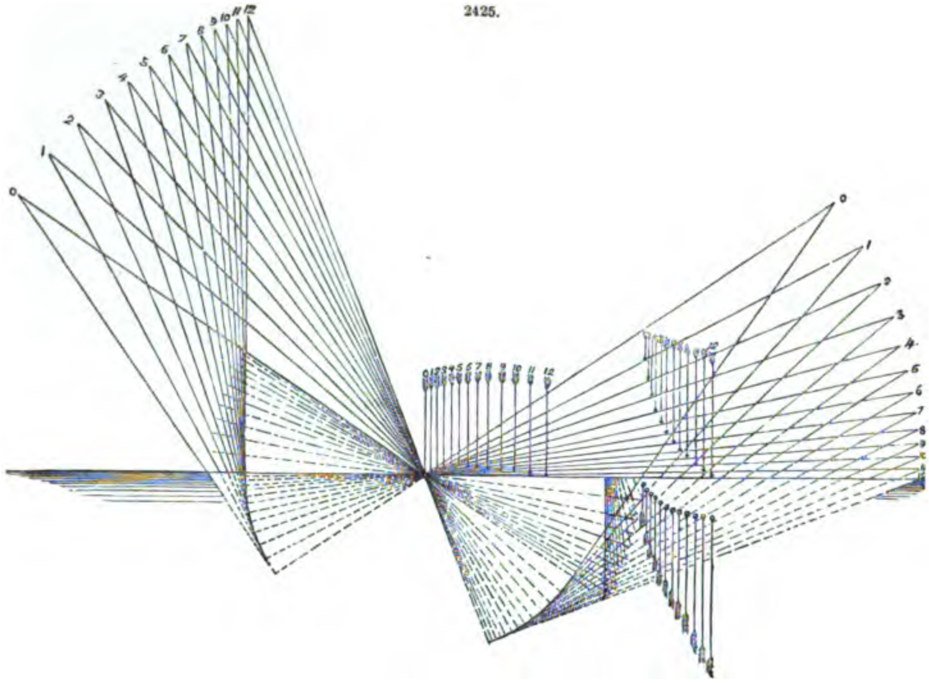
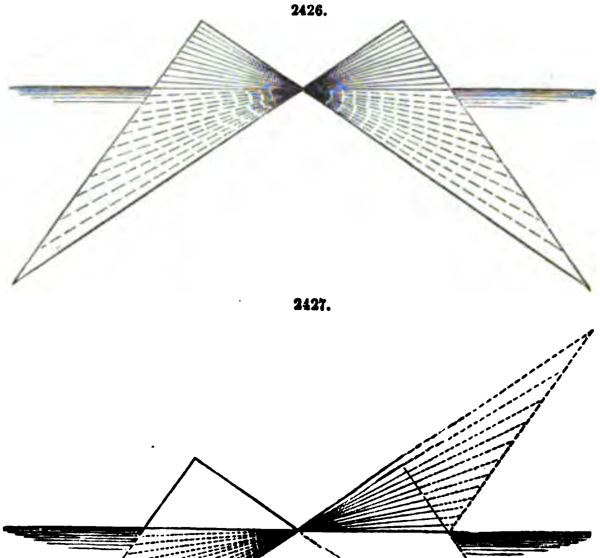


2426.



2427.

DISTANCES. Fr., *Distance;* Ger., *Entfernung;* Ital., *Distanze.*

Distances and heights determined without moving from a given point or station to any other point or station.

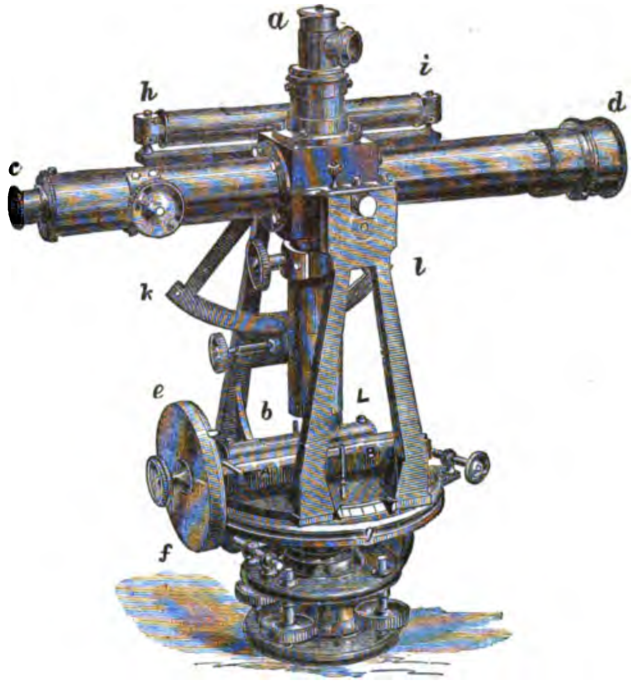
Eckhold's Geodesical Omnimeter, Fig. 2428.—This important mathematical instrument effects several geodesical operations; namely, the measuring of distances, whether inclined or horizontal; the determination of altitudes; and the measuring of angles, horizontally or vertically. In fact, this one instrument does the work more expeditiously than, and supersedes the use of, the chain, level, and theodolite.

Distances and altitudes may be obtained without changing the position of the instrument at one and the same time, by one single and unique operation; and that, too, with greater exactness and facility than by any other means which has hitherto been employed.

Distances of	100 ft.	are determined	exact to	0·001 of a ft.
"	1000 ft.	"	"	0·05	"
"	1000 yds.	"	"	1 ft.	
Heights at a distance of	300 ft.	"	"	0·0005 of a ft.	
" "	1000 ft.	"	"	0·002	"

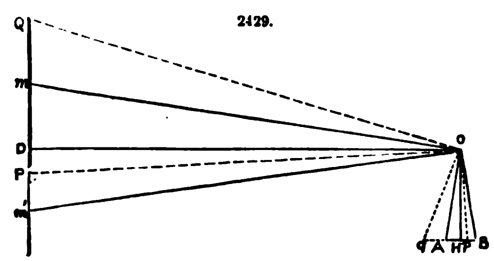
The instrument is formed by combining a powerful microscope $a\,b$, Fig. 2428, with a telescope $c\,d$, and a micrometer $e\,f$, which gives measures on a horizontal scale, divided in half millimètres, placed at A B, as fine as 0·0000002 of a mètre, or 0·0002 of a millimètre. The microscope $a\,b$ is perpendicular to the telescope $c\,d$, and both move on the same axis O. The perpendicular distance from the centre of the axis O to the scale A B can be found to any required degree of accuracy; it is a constant quantity in each instrument. The bases and the perpendicular of any number of triangles may be taken by the use of the microscope, micrometer, and scale A B, with accuracy, which triangles will be similar to corresponding ones taken by the telescope. The most important triangle given by the telescope is that formed by supposing two lines to pass through the telescope, one to the head and the other to the foot of a staff of known length, held perpendicularly at a point, the distance of which is required, or held perpendicularly in the direction of a required height. The similarity of the triangles here referred to may be established by plane geometry as follows;—

2428.



In Fig. 2429, if O D be perpendicular to O H, m O to O A, m' O to O B, and A B perpendicular to $m\,m'$; then the triangles $m\,m'$ O and A O B, m D O and A O H, m' D O and B H O are respectively similar. For the angles m'O H + H O B = m'O H + D O m' = a right angle; therefore, the angle H O B = D O m', and the triangles m' D O and B H O are similar, because the angles O D m' and O H B are right angles. In the same manner it may be shown that the right-angled triangles m D O and A H O are similar; and consequently the triangles $m\,m'$O and A O B are similar.

2429.



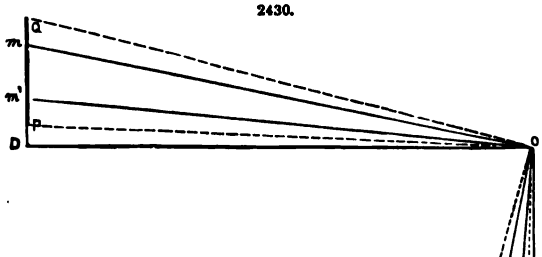
Hence we have the following proportion;—A B : O H :: $m\,m'$: O D; then O D, or the distance

$$= \frac{\mathrm{OH} \times m\,m'}{\mathrm{AB}}.$$

Again, A B : B H :: $m\,m'$: m'D; then m' D, where the perpendicular distance O D strikes $m\,m'$,

$$= \frac{m\,m' \times \mathrm{BH}}{\mathrm{AB}}.$$

2430.



When the horizontal distance O D is determined, any other height P Q in the direction of $m\,m'$ is readily found, for when the telescope is directed to P and Q, the microscope accurately determines $p\,q$; and as before shown, the triangles O P Q and O $p\,q$ are similar; then

$$\mathrm{OH} : pq :: \mathrm{OD} : \mathrm{PQ}; \;\therefore \text{ any height } \mathrm{PQ} = \frac{pq \times \mathrm{OD}}{\mathrm{OH}}.$$

Since O H may be put = 1, 10, 100, 1000, 10000, and so on, the calculation becomes extremely easy.

We shall take another case, Fig. 2430, where $m\,m'$ is placed above the horizontal line O D.

Then, as in the former case, $m'O$ is perpendicular to OB, mO to OA, and DO to OH. ABH being horizontal, it is parallel to DO and perpendicular to $Dm'm$.

$$\text{Therefore } \angle m'OH - \angle m'OD = \angle DOH \text{ a right angle;}$$
$$\text{and } \angle m'OH - \angle BOH = \angle BOm' \quad ,,$$

Hence, the angle $m'OD =$ the angle BOH; and as the angles D and H are right angles, the triangles $m'OD$ and BOH are similar.

In the same way it may be shown that the triangles mDO and AOH are similar.

Consequently, the triangles $mm'O$ and AOB are similar, and we have, as before,

$$AB : OH :: mm' : OD; \text{ therefore, the distance } OD = \frac{OH \times mm'}{AB}$$

The horizontal distance OD being found, any other height PQ in the direction of mm' is instantly obtained, for when the telescope is directed to P and Q, the microscope gives pq; then, as before shown in the other cases, the triangles OPQ and Opq may be proved to be similar; then $OH : pq :: OD : PQ$; therefore, any height as $PQ = \dfrac{pq \times OD}{OH}$.

Principal Parts of the Omnimeter, Fig. 2428.—1. A powerful telescope cd, connected with

2. A powerful microscope ab turning on the same axis O.
3. A scale AB divided into half millimètres, moved by
4. A micrometer-screw, with
5. A circular disk ef divided into 500 equal parts; one turn of this disk moves the scale half a millimètre, this is the limit of its range.
6. A graduated circle g for measuring horizontal angles.
7. A level, fixed on 6, to adjust the horizontal plane.
8. A second level hi which can be placed on the telescope cd.
9. An arc kl for measuring vertical angles, without which the instrument would be incomplete.

This instrument is portable and easily manipulated; its parts are readily controlled, adjusted, and rectified. Fig. 2428 is of an instrument manufactured by Elliott, Bros., London.

Accompanying the instrument there is a levelling staff mm', Figs. 2429, 2430, not divided but of an invariable length, which length is defined by two white lines or marks on a black ground, one at the upper extremity at m, and the other at the lower extremity m'.

Mode of Operating with the Omnimeter.—First; place the staff in a vertical position at one extremity of the line to be measured, and the instrument properly adjusted at the other end; care must be taken that the micrometer is at zero.

Secondly; direct the telescope to coincide with the upper line of the staff, and clamp it; then looking through the microscope at the scale, which is advanced and the fractional part of a division measured by turning the micrometer-screw; we thus place the line of the scale (the microscope reverses) between the two horizontal cross-lines of the microscope and ascertain the fractional part of the scale between that line and the cross-lines. For example, suppose the number on the scale pointed out by the microscope to be over 67, that is, something more than 67, we affix to the right-hand side of this number the value of the fraction which is given by the vernier of the micrometer; suppose this number to be 203·5 out of the 500 between each of the two consecutive divisions of the scale, then the reading would be 67203·5. Should we observe an unnumbered division, we note the quantity of the preceding line and add 500 to the quantity given by the micrometer-circle, because 500 parts of this circle equal half a millimètre.

Thirdly; a similar operation has to be performed when the lower white line on the staff is sighted; it may be here remarked that it is very essential to point with the telescope and microscope in the same manner.

Suppose on a second reading from a second sighting we pass the unnumbered division on the scale between 66 and 67, and obtain 1·5 from the micrometer-circle, the number 66501·5 = 66000 + 500 + 1·5 is obtained.

The operation with the instrument is now completed, and we are in possession of the required data from which distances and altitudes may be calculated.

To determine Distances.—Take the difference of the two readings, which is 1202, in the present example, for

$$\begin{array}{ll} \text{From} & 67203\cdot5 \\ \text{Take} & 66001\cdot5 \\ \hline \text{Gives} & 1202\cdot0 \text{ the difference.} \end{array}$$

1202·0 represents $0^{m}\cdot001202$ in parts of a mètre.

$$\begin{array}{ll} \text{For} & 67203\cdot5 = 0^{m}\cdot0672035 \\ \text{and} & 66001\cdot5 = 0^{m}\cdot0660015 \\ \hline & \qquad\quad 0^{m}\cdot0012020 \end{array}$$

$OH = 0^{m}\cdot15$, by the construction of the instrument, Figs. 2429, 2430.

$mm' = 10$ ft., the invariable length of the staff.

$AB = 0^{m}\cdot0012020$ or 12020, if $0^{m}\cdot15$ be put = 1500000.

Then referring to the proportions and Figs. 2429, 2430, we have the horizontal distance

$$OD = \frac{OH \times mm'}{AB} = \frac{0^{m}\cdot15 \times 10}{0^{m}\cdot0012020} = \frac{1500000}{12020} = 1247\cdot92 \text{ ft.}$$

It is evident that 1500000 becomes a constant quantity.

It is easily seen that the divisions of the scale of the micrometer may be of any convenient corresponding length, as they are only required to represent ratios, and may represent yards, mètres, or any other measure.

The base line of the instrument O H, measured from the point of rotation of the microscope, perpendicular to the scale, may be accurately determined by carefully measuring a distance from the instrument to the staff held in a perpendicular position, or O H may be found by a mathematical investigation. In finding the base line O H, we must be convinced that the optical axes-lines of the microscope and telescope are in the same vertical plane, or rather in parallel vertical planes, perpendicular to each other. To effect this adjustment we sight firstly, a staff of 10 ft.; and secondly, of a shorter length, say for example one of 5 ft., at the same distance, and see with the acquired data if the base line O H of the instrument remains in each case proportional to the distance; should this not be, the cross-lines of the microscope must be moved by the motion of their adjusting screw.

Levelling.—The manner of levelling consists in determining the lines A B and B H on the scale of the instrument; the first being proportional to the staff, and the other to the altitude or the height over or under the level of the instrument. The first of these lines, A B, we find, as before described, by sighting the staff; the second, B H, by determining on the scale the point H, called the stationary point of the scale, which is given by the optical axis-line of the microscope, when the telescope is brought horizontal by means of the level attached to it. The point H, marked (8), is constant and serves for all calculations in levelling operations; suppose, for example, (8) to be at 500010, on the scale, we then have the line B H by the difference between the number B acquired by sighting the staff, and the number of the stationary point H which, in the example that we have taken, gives

$$\begin{array}{r} 660015 \\ 500010 \\ \hline 160005 = \text{B H}. \end{array}$$

Then by substituting in the proportion, we have,

$$m'\text{D} = \frac{m\,m' \times \text{B H}}{\text{A B}} = \frac{10 \text{ ft.} \times 160005}{12020} = +\,133 \cdot 115 \text{ ft.}$$

The heights are termed positive or negative according as the scale readings are greater or less than the stationary point. We have adopted the following simple tabulated form for noting the readings when distances and altitudes are being measured.

Staff 10 ft.	From the Scale.	Omnimeter.		Levelling.			Observations.
		Constant of Distance.	Distance in feet.	Starting-point 8.	Height in feet.		
Upper line	672035	15000000		500010	+	−	
Lower line	660015			660015			
	12020		1247·92	160005	133·115		

To avoid dividing the constant dividend, we may construct a small table, from which, by mere inspection, the distances may be taken.

Advantages of the Omnimeter.—First. That, having a constant starting-point for levelling, we have nothing further to do with the collimation of the optical axis of the telescope.

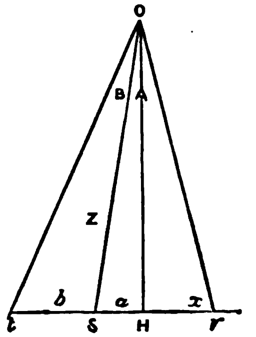
Second. That we are enabled to measure and to level at very long distances on horizontal or on inclined planes.

Third. That we have but one and the same unique operation for measuring both altitudes and distances.

Fourth. That the operator, always pointing the telescope on the same two well-defined lines of a staff of a known length, has not the same hesitation in reading as with an ordinary levelling staff, with which there is an element of guess-work not found in using the staff of the omnimeter.

The length of the base, O H, of the instrument, and the position of the neutral point, 8 or H, on the scale, may be determined mathematically as follows, without resorting to experiments.

2431.



Let $r\,s = a$, Fig. 2431, any distance measured on the scale, subtending the known angle A.

$s\,t = b$ any convenient distance measured in continuation, subtending the angle B.

Then put x = the unknown angle O r H, and Z = the unknown line O s.

Then we have

$$a : \text{Z} :: \sin. \text{A} : \sin. x;$$

$$\text{and} \quad \text{Z} : b :: \sin. (\text{A} + \text{B} + x) : \sin. \text{B};$$

$$\therefore \quad a : b :: \sin. \text{A} \sin. (\text{A} + \text{B} + x) : \sin. \text{B} \sin. x$$

$$\therefore \quad b \sin. \text{A} \sin. (\text{A} + \text{B} + x) = a \sin. \text{B} \sin. x.$$

$$\text{But sin. } (A + B + x) = \text{sin. } (A + B) \cos. x + \cos. (A + B) \text{ sin. } x,$$

$$\therefore\ b \text{ sin. } A\,[\text{sin. } (A + B) \cot. x + \cos. (A + B)] = a \text{ sin. } B;$$

$$\therefore\ \text{sin. } (A + B) \cot. x = \frac{a \text{ sin. } B}{b \text{ sin. } A} - \cos. (A + B);$$

$$\therefore\ \cot. x = \frac{a \text{ sin. } B}{b \text{ sin. } A \text{ sin. } (A + B)} - \cot. (A + B).$$

Hence x becomes known; and since sin. $(A + B) : (a + b) ::$ sin. $(A + B + x) : ro$,

$$\therefore\ ro = \frac{(a + b) \text{ sin. } (A + B + x)}{\text{sin. } (A + B)}; \text{ and consequently,}$$

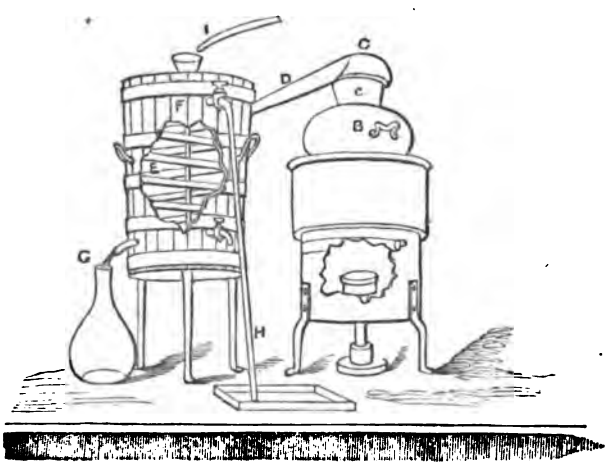
$$r\mathrm{O} \text{ sin. } x = \mathrm{OH} = \frac{(a + b) \text{ sin. } (A + B + x) \text{ sin. } x}{\text{sin. } (A + B)}$$

$$\text{and}\quad r\mathrm{H} = r\mathrm{O} \cos. x = \frac{(a + b) \text{ sin. } (A + B + x) \cos. x}{\text{sin. } (A + B)}.$$

DISTILLING APPARATUS. Fr., *Appareil distillatoire;* Ger., *Destillations Apparat;* Ital., *Apparecchia distillatore;* Span., *Aparato de destilacion.*

Distillation is the volatilization of a liquid in a closed vessel by heat and its subsequent condensation in a separate vessel by cold. The term is principally applied to the operation of extracting spirit from a substance by evaporation and condensation.

2432.



Destructive distillation is the distillation of substances at very high temperatures, so that the ultimate elements are separated or evolved in new combinations.

Dry distillation, the distillation of substances by themselves, or without the addition of water.

The apparatus commonly used consists of a copper boiler B, Fig. 2432, for holding the liquid to be distilled; C the head of the still, which is movable, lifts out at *c*, and is connected by D with the worm E. The worm is a pewter pipe coiled round in a tub F, and issuing at G. The steam fron the boiler passing into the worm is condensed to the liquid state, being cooled by the water in contact with the worm; this water, becoming heated, passes off through the pipe H, and is replaced by cold water which is allowed to enter through I.

The Distillery of W. Macfarlane, of Glasgow, is one of the largest distilleries of the kind; it contains a great number of the most modern arrangements, all executed on a very large scale. The production of alcohol, in its abstract scientific principle, is the conversion of the starch contained in flour or grain into grape-sugar, and the subsequent conversion of this sugar into alcohol and carbonic acid. The conversion of starch into sugar is a mere change of arrangement of atoms, as far as chemistry is able to teach at present, that is, the starch and sugar contain the same elements—carbon, hydrogen, and oxygen—in the same percentage and proportion, only differently arranged, as we are not allowed to say crystallized with regard to a substance like starch. The conversion of starch into sugar is an effect of simple heat and moisture, and may be brought about in two ways. First, the slow action of the process of growth, by bringing the grain into a similar condition in which it commences growing in the soil, and checking this growth by drying when the percentage of sugar has arrived at its maximum; this is the operation of malting. The quicker process is the mashing of unmalted or raw grain, mixed with a certain proportion of malt, the diastase of the latter effecting the necessary conversion of the unmalted grain. In Macfarlane's distillery both processes are in use, and most of the spirits are made from a combination of malted and raw grain. The grain, after the process of growing, or the other preliminary operations of this growing process, must be dried, and this is effected in the malting kiln. The simplest form of kiln has a large floor of perforated bricks or tiles, upon which the malt is spread and exposed to the heated air arising from a fire below this floor. The perforated bricks have in more recent time been replaced by cast-iron plates, having a series of narrow slots or perforations for the transmission of the heated air. An arrangement of malting kilns in superposed stories or floors is carried out in Macfarlane's distillery, which is very economical in space, and probably also in fuel. There are three superposed floors, each perforated in the usual manner, and fitted in the centre with one or two discharging holes. The fire is in the ground floor below these kilns, and the fresh malt is brought upon the highest level, or top floor, first of all. The heated air, rising through all the

kilns, evaporates the gross bulk of the water, and, after a number of hours, the grain from the upper floor is discharged into the lower one through the central discharging hole, the contents of the second kiln being previously discharged into the lowest compartment nearest to the fire, where the malt is finally dried and removed ready for use. There are some difficulties in working these kilns, arising from the necessity of passing the steam formed by the malt in the lower chambers through the grain spread over the upper floors; but, as a whole, these three-story kilns work very well, and save much space as compared with single kilns. An extraordinary drying kiln is that used by Macfarlane for drying the unmalted grain. This is a large square building, carrying a perforated floor about 30 ft. or 40 ft. above the ground, and having no other floors or partitions throughout this entire height. Below the perforated floor an open passage is left for heated air, which is driven through at high speed by means of a large fan, and ascends through the floor and through the grain spread over it. The grain, when dried, is discharged through trap-doors or holes in the floor, and falls into the large space below, where it is allowed to accumulate up to the height of the air-passages, say within a few feet from the drying floor. This enormous store of dried grain forms a kind of pressure reservoir, delivering grain in a continuous stream from its bottom through tubular passages fitted with Archimedian screws. This kiln can dry 1200 to 1500 bolls of grain per day. The fan we understand to be 14 ft. diameter, and the heating of the air is effected by its being passed over a series of pipes heated by steam, the air outside and the steam inside the pipes moving in opposite directions. One of the most imposing articles in this distillery is the vessel in which the malt is mixed with hot water or mashed. This is a cast-iron cylinder 30 ft. in diameter and 8 ft. deep to a perforated false bottom, the real bottom being some inches below this. In the centre is a column round which a set of mechanical mixers turn and revolve, driven by gearing working in a circular rack, which runs all round the circumference of this large vessel. The capacity of this vessel is 30,000 gallons, and it is filled with fresh materials every six or eight hours. The capacity of this vessel virtually gives the limit of the productive power of this establishment, as all the material converted into spirits there must pass through this apparatus. The function of the mashing process is to extract the sugar from the grain by dissolving it in water, and to draw off the wort or saccharine liquor ready for fermentation. The liquor, as drawn from this vessel, is pumped into fermenting vats made of wood, and hooped with iron. There are numerous vessels of this kind in this distillery, each holding from 9000 gallons upwards; but the most remarkable fermenting vats are two vessels of extraordinary size, each capable of holding 52,000 gallons of liquor. The fermentation is a process in which no mechanical means are employed. The sugar, under the influence of a moderate temperature, and stimulated by the action of yeast, decomposes spontaneously, and, without taking up any other element from either air or water, is divided into alcohol and carbonic acid, these two substances, when added together upon paper, making up the composition of sugar, although, in reality, no chemist has ever succeeded in producing sugar from these two substances. The wort filled into the fermenting vat yields about 10 per cent. of refined spirits, but for obtaining these latter it is necessary to separate the alcohol from the rest of the liquor by means of distillation. This last process effects no chemical change; its *rationale* is simply to separate the more volatile alcohol from the less volatile liquor in which it is contained, by raising the mixture to a temperature which is above the boiling-point of the first, and below that of the second substance. The old and primitive mode of operation consists in using a large still made of copper, and communicating with a condenser, and heating this still by means of the direct action of a fire maintained below it. The second and more modern form is to distil the alcohol by means of steam, which passes through a series of cellular vessels through which the fermented liquor is slowly moving in a continuous stream. The action of this system is continuous, and far more under control than the former. Nevertheless, both systems are at present in use, and must be simultaneously maintained to meet the demand for different kinds or differently-flavoured spirits. The distillation by direct heat produces the Irish whisky, which is without doubt the best whisky in the world; while the other method yields Scotch whisky. The difference is very material, as the former spirit contains a series of volatile products besides alcohol, which are removed from the product in the process of distillation by steam. The most noteworthy amongst these admixtures of Irish whisky is a small percentage of fusel oil, a spirit of similar composition to that of alcohol. It is obvious, therefore, that the flavour of some kinds of spirit is bought at a high price, as far as their effect upon the health of the consumer is concerned. There is, however, no marketable spirit entirely free from volatile products different from alcohol, most of which are of a less noxious character than fusel oil. A new set of stills for Irish whisky has recently been set to work at Macfarlane's distillery. It consists of three copper stills, delivering their products from one to the other in succession, so as to distil the product three times over. The first still, containing the fresh liquor from the fermenting vat, has a capacity of 13,690 gallons; the second still holds 6820 gallons of weak spirits, and the third still has 4620 gallons measurement. This whole plant is of a very striking appearance, and executed with great nicety of workmanship.

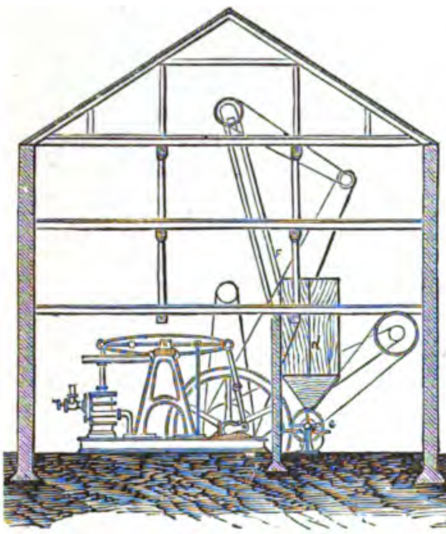
Figs. 2433 to 2436 are transverse sections of this distillery.

These illustrations represent a 20-qr. mashing plant, equivalent to the production of about 2000 gallons of spirits in the usual weekly distillery period. It is arranged to work entirely with steam, and to have no pumping, except that of the worts, from the underback to the refrigerator. In the engravings the refrigerator is shown over the fermenting backs, but it may be placed with equal advantage in proximity to the underback. The cooling floor is not shown, as it is quite unnecessary where a Morton refrigerator can be applied.

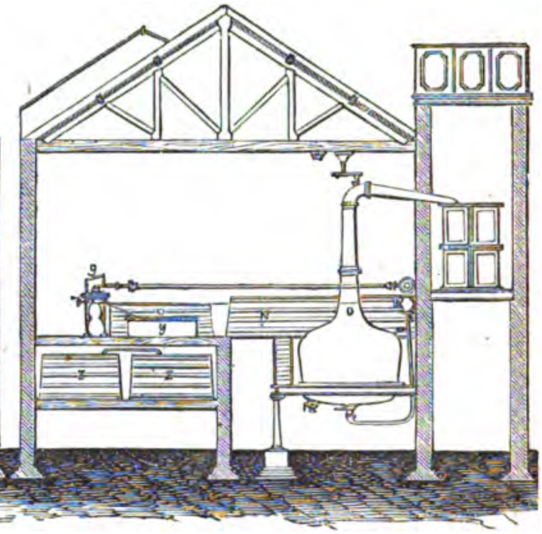
Beneath the malt-stores are the steam-engine, steam-boilers, and malt-mills. The malt being kept under bond, the commencement of a period begins by giving the excise officer notice to grind, and the malt is measured out in his sight into the unground malt hopper. From this it descends to be crushed in the mill *e*, rising by means of elevators to ground malt hopper *g*. For the sake of the general reader, we may mention that the grinding is all performed under lock and key (the

miller being locked up in the mill), and a fresh notice is required before the malt can be used in mashing. The mashing process is exactly the same as that performed in breweries; the malt falling from the hopper, meets, in the intermediate masher *h* with the hot water, and when the two have properly mingled together they fall into the mash tun *j*, where they are still further amalgamated. The proper heat at which the malt is wetted, and at which the contents of the mash tun stand when finished, furnishes the key to this operation. After resting for a time to allow of the conversion of the malt into sugar, the extract is allowed to drain off into the under-back *k*, which, in the plans shown, is intended to act as a jack-back, and is large enough to allow of the worts being declared in it before being pumped to the fermenting backs. It is likewise

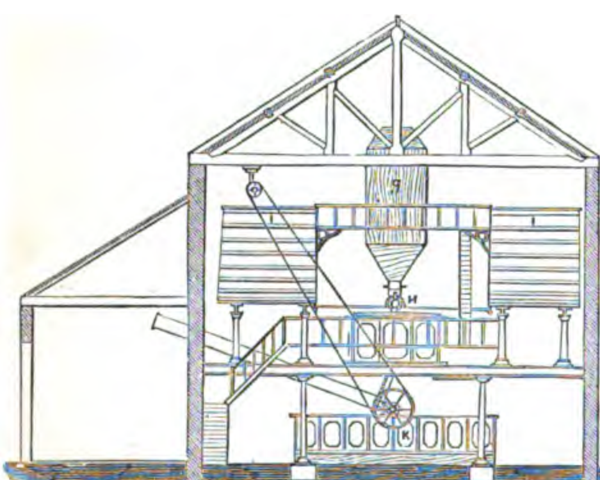
2433.



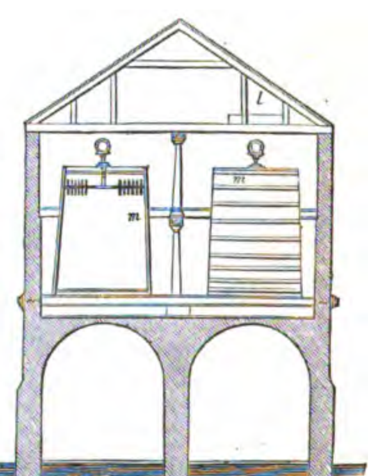
2434.



2435.



2436.



proposed that the sprinkling system, as practised by brewers, be employed to complete the extraction of the goods after the first mashing; and this being the case, the sprinkling on of hot water over and the draining off the wort from below the goods would continue until the gravity assumed for declaration (generally about 10·50) was reached. When a sufficient quantity has been got off for fermentation, the goods are mashed up again, and re-drained so long as any extract remains. These weak drainings are pumped into the sparge-back *i* (or, as the Excise have it, brewing copper), and heated up for use in place of water in the next day's mashings. In passing, it may be remarked that the sprinkling system ought to be fully adopted in malt distilleries, as with it in declaring at a gravity of 1·050 all extract of any use can be taken off the malt, and

sparges, with their very doubtful advantages, done away with, or, at all events, reduced to within lower limits than is the case at present.

To return to the circle of operations, after declaration of quantity and strength, the wort is pumped to the refrigerator *b*, by the wort-pump attached to the steam-engine, and cooled to from 68° to 78° Fahr. (according to the size of the wash-back), and run into the wash-backs *m m m*, and 2 per cent., or thereabouts, of yeast added. The fermentation is completed in from 36 to 72 hours, all the saccharine matter being converted into alcohol; and the wort, which stood at a specific gravity of 1·050, standing as wash at the gravity of water, 1000, or even under, when the attenuation has been perfect.

In due course the wash is run into a wash-charger, its attenuation having been declared for distillation. From the wash-charger the wash-still *o* is charged, and evaporation began as soon as possible. The evaporated products pass into the worm *p*, whence, being condensed, they run across the still, the house, through the safe *q*, into the low-wine receiver *r*. From the low-wine receiver *r* the feint-still *s* is charged; and the charge, evaporated and condensed in the worm *t*, is run through the safe into the feints receiver *u*. From the feints receiver *u* the spirit-still *v* is charged: and the charge evaporated, and condensed in the worm *w*, is, like the others, run through the safe, and into the spirit receiver *y*, a marketable article. From *y* it is again declared as to the strength and quantity, and run into the cellar vats *z z*, and again racked off into casks for consumption and bonded in duty-free warehouses.

While this is the routine from vessel to vessel between fermenting-back to spirit-store, yet the fact is that no two parts of the country pursue exactly the same practice. In the Highlands, where high-flavoured whisky is wanted and made, a large portion of the spirit is taken from the low-wines; while in the Lowlands, where a plain spirit is made, it is taken mostly from the feints. The arrangements of this distillery provide for a mixture of clear low-wines and feints to produce the spirit.

The foul and weak distillates from wash and feints stills are retained in the low-wine receiver for further distillation, the clear and strong products only going forward to the feints receiver, to charge the spirit-still; the latter still is placed so high that the feints from it gravitate back to the feint-still, and are accounted for in the stock at the end of the period.

The purification of spirit by repeated boiling results in the constant decrease of the boiling-point, as it increases in purity; and, of course, as the boiling-point lowers, towards that of pure alcohol, or 173° Fahr., so is the distiller enabled to separate the distillates coming off at low temperatures from those which require a higher temperature to cause them to evaporate.

Inattention to, and ignorance of, the principles involved in the evaporation of the various substances of vegetable origin, mixed up with distilling wash, is the principal cause of so much vile-flavoured and unwholesome, or, in fact, poisonous material, under the name of spirit, being brought into the market.

Distilled Spirits.—The varieties of ardent spirits are obtained from fermented liquids by distillation, so that they consist essentially of alcohol more or less diluted with water, and flavoured either with some of the volatile products of the fermentation, or with some essential oil added for the purpose.

Brandy is distilled from wine, and coloured to the required extent with burnt sugar (caramel). Its flavour is due chiefly to the presence of œnanthic ether derived from the wine. The colour of genuine pale brandy is due to its having remained so long in the cask as to have dissolved a portion of brown colouring matter from the wood, and is therefore an indication of its age. Hence arose the custom of adding caramel, and sometimes infusion of tea, to impart the astringency due to the tannin dissolved from the wood by old brandy.

Whisky is distilled from fermented malt which has been dried over a peat fire, to which the characteristic smoky flavour is due.

Gin is also prepared from fermented malt or other grain, and is flavoured with the essential oil of juniper, derived from juniper berries, added during the distillation.

Rum is distilled from fermented molasses, and appears to owe its flavour to the presence of butyric ether, or of some similar compound.

Arrack is the spirit obtained from fermented rice.

Kirschwasser and *maraschino* are distilled from cherries and their stones, which have been crushed and fermented.

Some varieties of British brandy and whisky are distilled from fermented potatoes, or from a mixture of potatoes and grain, when there distils over, together with ordinary alcohol, another spirit belonging to the same class, but distinguished from alcohol by its nauseous and irritating odour. This substance, which is known as *potato-spirit*, *amylic alcohol*, or *fousel oil* ($C_{10}H_{12}O_2$), also occurs, though in very minute quantity, in genuine wine-brandy. The manufacturers of spirit from grain and potatoes remove a considerable part of this disagreeable and unwholesome substance by leaving the spirit for some time in contact with wood-charcoal.

Alcohols and their Derivatives.—The alcohols are all composed of carbon, hydrogen, and oxygen; the members of the series represented by common alcohol always contain two equivalents of oxygen, and two more equivalents of hydrogen than of carbon. The number of equivalents of carbon and hydrogen is always an even number, so that the *general formula of an alcohol of this series* may be written thus, $C_{2n}H_{2n+2}O_2$. Thus, in ordinary or *vinic* alcohol, $C_4H_6O_2$, $n = 2$; in wood-spirit or *methylic* alcohol, $C_2H_4O_2$, $n = 1$; in potato-spirit or *amylic* alcohol, $C_{10}H_{12}O_2$, $n = 5$.

These alcohols constitute, therefore, a truly homologous series, of which many members, however, remain to be discovered.

The following Table includes the alcohols of this series which are at present known:—

Chemical Name.	Source.	Equivalent Formula.	Common Name.
1. Methylic alcohol ..	Destructive distillation of wood	$C_2H_4O_2$	Wood naphtha.
2. Ethylic " ..	Vinous fermentation of sugar	$C_4H_6O_2$	Spirit of wine.
3. Propylic " ..	Fermentation of grape-husks	$C_6H_8O_2$	
4. Butylic " ..	Fermentation of beet-root	$C_8H_{10}O_2$	
5. Amylic " ..	Fermentation of potatoes	$C_{10}H_{12}O_2$	Fousel oil.
6. Caproic " ..	Fermentation of grape-husks	$C_{12}H_{14}O_2$	
7. Œnanthic " ..	Distillation of castor-oil with potash ..	$C_{14}H_{16}O_2$	
8. Caprylic " ..	Fermentation of grape-husks	$C_{16}H_{18}O_2$	
10. Rutic " ..	Oil of rue	$C_{20}H_{22}O_2$	
12. Lauric " ..	Whale oil	$C_{24}H_{26}O_2$	
16. Cetylic " ..	Spermaceti	$C_{32}H_{34}O_2$	Ethal.
27. Cerylic " ..	Chinese wax	$C_{54}H_{56}O_2$	Cerotine.
30. Melissic " ..	Beeswax	$C_{60}H_{62}O_2$	Melissine.

The usual gradation in properties attending the gradation in composition among the members of a homologous series, is strikingly exemplified in the class of alcohols. The first eight members of the group, linked together as they are by an almost common origin (being derived, with one exception, from the fermentation of substances nearly allied, and that exception being a product of destructive distillation which may be regarded as an accelerated fermentation), and by a regularly ascending composition, would be expected to resemble each other in their properties far more closely than the other members of the class. Accordingly we find that methylic, ethylic, propylic, butylic, amylic, caproic, œnanthic, and caprylic alcohols, are all liquid at the ordinary temperature, that they all possess peculiar and powerful odours, and may be readily distilled unchanged. Among these, however, the gradation is not to be overlooked. The two first, methylic and ethylic alcohols, may be mixed with water in all proportions; but the third, propylic alcohol, though freely soluble in water, is not so to an unlimited extent; whilst butylic alcohol is less soluble, and amylic alcohol may be said to be sparingly soluble in water. Caproic alcohol, the next member, is insoluble in water: whilst caprylic is not only insoluble, but possesses an oily character, leaving a greasy stain upon paper.

In their boiling-points, and the specific gravities of their vapours, a similar gradation is observed.

Alcohol.	Boiling-point.	Vapour Density.
	°	
Methylic	149·9 F.	1·12
Ethylic	173	1·61
Propylic	205	2·02
Butylic	233	2·59
Amylic	269·8	3·15
Caproic	299–309	3·53
Œnanthic	327–343	..
Caprylic	356	4·50

One equivalent of each of these alcohols yields *four volumes* of vapour; or, in other words, if a given weight of the alcohol corresponding to its equivalent number be converted into vapour, that vapour will occupy four times as much space as would be occupied by an equivalent of oxygen at the same temperature and pressure, or twice the space occupied by an equivalent of hydrogen, or of water converted into vapour under the same conditions.

The higher members of the group of alcohols are solid fusible bodies more nearly approaching to waxy or fatty matters in their nature, and not susceptible of distillation without decomposition. Far less is known of these than of the alcohols containing less carbon.

Wood charcoal presents features which arrest attention on account of its specific properties, as of the influence exercised by the method adopted for obtaining it, upon its fitness for the particular purpose which it may be destined to serve.

If a piece of wood be heated in an ordinary fire it is speedily consumed, with the exception of a grey ash consisting of the incombustible mineral substances which it contained: if the experiment were performed in such a manner that the products of combustion of the wood could be collected, these would be found to consist of carbonic acid and water; woody fibre is composed of carbon, hydrogen, and oxygen ($C_{12}H_{10}O_{10}$), and when it is burnt, the oxygen, in conjunction with more oxygen derived from the air, converts the carbon and hydrogen into carbonic acid and water. But if the wood be heated in a glass tube, closed at one end, it will be found impossible to reduce it, as before, to an ash, for a mass of charcoal will remain, having the same form as that of the piece of wood; in this case, the oxygen of the air not having been allowed free access to the wood, no true combustion has taken place, but the wood has undergone *destructive distillation*, that is, its elements have arranged themselves, under the influence of the high temperature, into different forms of combination, for the most part simpler in their chemical composition than the wood itself, and capable, unlike the wood, of enduring that temperature without decomposition; thus, it is

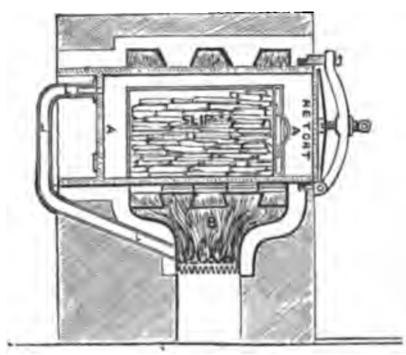
merely an exchange of an unstable for a stable equilibrium of the particles of matter composing the wood.

The vapours issuing from the mouth of the tube will be found acid to blue litmus paper; they have a peculiar odour, and readily take fire on contact with flame. The charcoal which is left is not pure carbon, but contains considerable quantities of oxygen and hydrogen, with a little nitrogen, and the mineral matter or ash of the wood.

When the charcoal is to be used for fuel, it is generally prepared by a process in which the heat developed by the combustion of a portion of the wood is made to effect the charring of the rest. With this view the billets of wood are built up into a heap, Fig. 2437, around stakes driven into the ground, a passage being left so that the heap may be kindled in the centre. This mound of wood, which is generally from 30 to 40 ft. in diameter, is closely covered with turf and sand, except for a few inches around the base, where it is left uncovered, to give vent to the vapour of water expelled from the wood in the first stage of the process. When the heap has been kindled in the centre, the passage left for this purpose is carefully closed up. After the combustion has proceeded for some time, and it is judged that the wood is perfectly dried, the open space at the base is also closed, and the heap left to smoulder for three or four weeks, when the wood is perfectly carbonized. Upon an average 22 parts of charcoal are obtained by this process from 100 of wood.

2437

2438.



A more economical process for preparing charcoal from wood consists in heating it in an iron case or *slip*, F, Fig. 2438, placed in an iron retort A, from which the gases and vapours are conducted by the pipe L into the furnace B, where they are consumed.

The infusibility of the charcoal left by wood accounts for its very great porosity, upon which some of its most remarkable and useful properties depend. The application of charcoal for the purpose of sweetening fish and other food in a state of incipient putrefaction has long been practised, and more recently charcoal has been employed for *deodorizing* all kinds of putrefying and offensive animal or vegetable matter. This property of charcoal depends upon its power of absorbing into its pores very considerable quantities of the gases, especially of those which are easily absorbed by water.

Dr. Normandy's Marine Aërated Fresh-water Apparatus.—Fig. 2439 is a front elevation of the apparatus.

Fig. 2440 is an end view of the apparatus.

Fig. 2441 is a back elevation of the apparatus.

Fig. 2442 is a plan of the apparatus.

Fig. 2443 is a vertical section of the evaporator, condenser, and refrigerator of the apparatus.

Fig. 2444 is a sectional plan of the apparatus.

In all the drawings the same letters represent the same parts.

A shows the entrance-pipe for the sea water. When the apparatus is put on board under the water-line, as is the case generally with steamers, this pipe is connected to a large cock communicating with the sea through the sides of the ship. When the apparatus is placed on deck, as is generally the case with sailing ships, or on land, this pipe is flanged to a much smaller pipe connected with a pump, by means of which the apparatus is supplied with water from the sea. In the first case, on opening the large cock to which this pipe is connected, or, in the second case, on working the pump, the sea water at once penetrates into the refrigerator B. The pipe A extends, as is seen, the whole length of the refrigerator, merely for the purpose of allowing of the apparatus being connected as occasion may require.

a, Figs. 2441 2442, and 2444, is a large pipe connecting the refrigerator B with the condenser D, so that the sea water entering from the sea through A passes through *a*, and thus fills up the condenser D, and through pipe F feeds the evaporator H, by means of pipe G', Fig. 2439, from the feed-box G, also Fig. 2439.

B, box or refrigerator. It is a horizontal cylinder, the construction of which is shown in Figs. 2443, 2444; the sea water being introduced first into this refrigerating cylinder, and consequently in its coldest state, circulates round a sheaf of pipes *k k*, Fig. 2443, between the caps C C, Figs. 2443, 2444, and cools the water which has been condensed in the tubes of the evaporator H and of the condenser D.

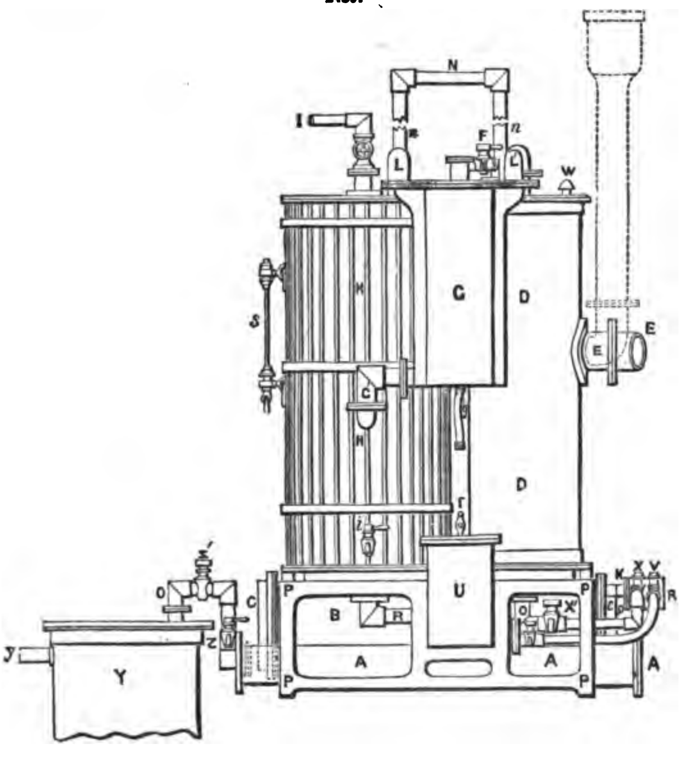
C, caps of the refrigerator B, so arranged, as may be seen in Fig. 2443, that by means of the divisions reserved in the said caps, the condensed water is made to traverse to and fro through the

different rows of pipes *kk*, Fig 2443, consecutively. From this refrigerating cylinder B the sea water passes through the pipe *a*, Figs. 2441, 2442, and 2444, into the evaporator H.

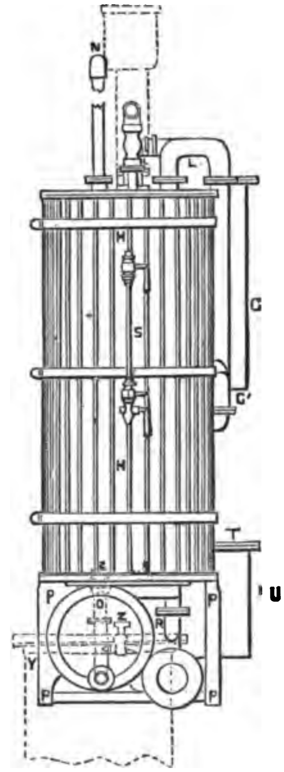
D, condenser. It is a cylinder containing another sheaf of pipes *m*, Fig. 2443, fastened between two caps M, Fig. 2443, and into which tubes *m* the aërated steam from the evaporator H is condensed by the sea water of the said condenser, and surrounding the said pipes *m*, Fig. 2443.

E, large outlet-pipe, which, when the apparatus is put below the water-line, as is generally the case in steamers, communicates with the sea through the sides of the ship by a large cock. When the apparatus is placed on deck, as is generally the case with sailing ships, or on land, this large pipe is turned-upwards, as represented by the dotted lines, and lengthened, so that the water which is forced through the apparatus by means of the pump, or otherwise, may be raised a few feet above the whole apparatus, so that the level of the sea water may be above the feed-pipe F. This turned-up pipe is connected by means of a flange, or otherwise, to a smaller pipe *c*, Fig. 2441, of about the same diameter as that of the suction-pipe of the pump, and a portion of the sea water originally pumped or let in is thus returned to the sea. This flow should be such that the condenser may remain hot down to the point whence pipe E protrudes. This circulation on board steamers, or whenever the apparatus is placed below the sea-level, is kept up by the difference of temperature of the sea water, which is hotter at E than it is at A. When the apparatus is placed on deck or on land, the circulation is of course kept up by the pump.

2439.



2440.



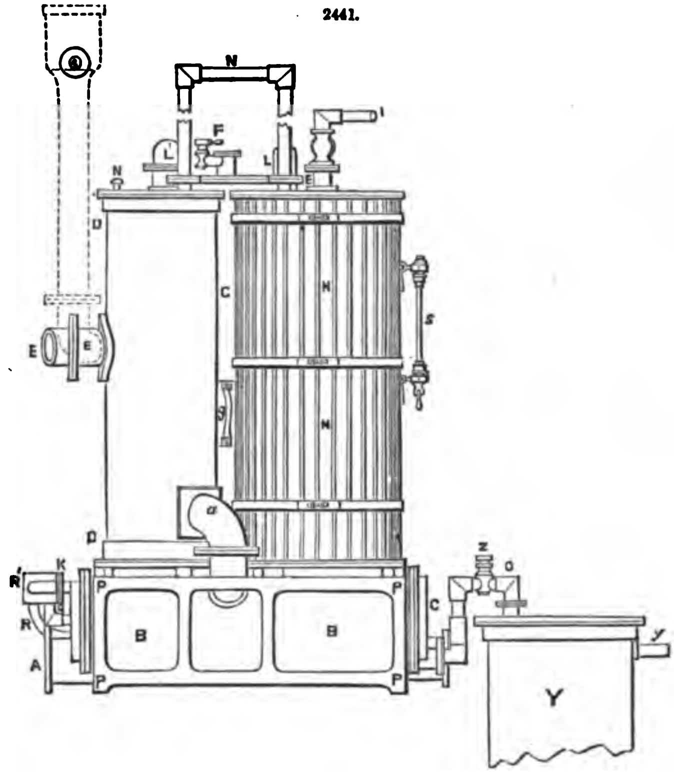
e, overflow-pipe for the escape of the excess of sea water, which it is necessary to pump through the apparatus when it is placed on deck, or on land—that is to say, when it is erected higher than the natural level of the sea.

F, feed-pipe inserted into the condenser D. The apparatus being placed below the level of the sea, as on board steamers, or below that of the sea water in the large turned-up pipe in which it is forced by a pump, as we have already said in explaining letter E, the water will naturally rise to the top of the condenser, and up the stand or arch pipe N, up to the level *n*, Fig. 2443, of the sea water round the ship, or of the sea water in the turned-up pipe E *e*, marked in dotted lines; and as the steam from the evaporator enters the sheaf of pipes from the condenser D, at the top of the said condenser, the temperature there is kept as high as 206°, and even sometimes 208° Fahr.; the temperature gradually decreasing towards the bottom of the apparatus. This feed-pipe F is provided with a cock, which is generally left open while the apparatus is at work, and it is through it that the hot water from the top of the condenser is led into the priming and feed box G.

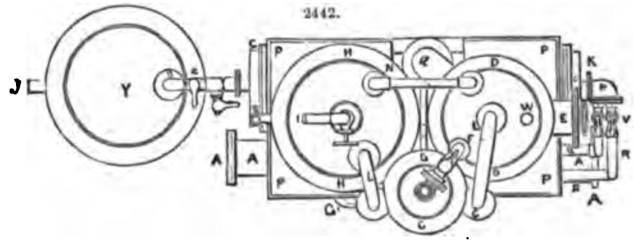
G, priming and feed box It is a box into which any salt which might be mechanically projected by ebullition is arrested and carried back again by pipe G' into the evaporator H. This priming box contains a float provided with a valve, and so adjusted that when the evaporator is filled with the proper quantity of sea water, the float, being buoyed up, will close the valve, and

thus prevent the flow of any more salt water into it: on the contrary, when the level of the sea water in the evaporator, by reason of the water evaporated, or of the brine which flows constantly therefrom through cock *i*, becomes reduced below the proper point, the float, sinking in the box, opens the valve, and more salt water is then admitted through the pipe F into the box G, and thence through the pipe G' into the evaporator, so as to restore the proper level. This pipe F is provided with a cock, which is placed there merely for the purpose of effectually stopping the flow of the sea water into the condenser when the apparatus is not at work, and likewise in order that, in case the float, or the valve of the float, should become damaged or out of order, the working of the apparatus may continue in a perfect manner, the necessary supply of salt water to be admitted into the evaporator being then regulated by hand. The tail of the valve is covered with a disc of vulcanized india-rubber *g*, so that on pushing the caoutchouc covering with the finger, the operator may be enabled, at any time, to feel whether the float is acting properly.

2441.



2442.



g is a sheath or tube of vulcanized india-rubber, into which a guiding rod attached to the lower part of the float is hanging freely, so that by grasping that guiding rod through the tube of india-rubber, the operator may freely move the float to which it is attached up and down, or rotatorily, in order to ascertain whether it is acting properly or not, or for the purpose of disengaging any impurity which might have accidentally lodged between the valve and its seat.

H, evaporator or cylinder, containing the evaporating tubes and the sea water, part of which has to be evaporated, Fig. 2443. This cylinder is felted over and covered with wood, or otherwise, to prevent loss of heat by radiation.

I, steam-pipe from a boiler, leading the steam thereof, more or less under pressure, into the vertical evaporating tubes of the evaporator H.

i, brine-cock, which is left constantly open to a certain extent while the apparatus is at work, so as to prevent saturation and incrustation, by allowing a constant discharge of sea water.

J, Fig. 2443. *j*, Fig. 2443.

K, flange uniting the refrigerator B with the mixing pipe R', into which the condensed non-aërated fresh water of the pipe R from the evaporator, and the condensed aërated fresh water of the pipe Q from the condenser are led, so that the mixture of these two fresh waters may be refrigerated. *k k*, Fig 2443.

L, pipe conducting the mixture of steam and air from the evaporator H into the priming and feed box G, and thence through pipe L' into the condensing tubes within the condenser D.

L', pipe conducting the mixture of steam and air from the priming box G into the tubes within the condenser D; the steam having first deposited in the said priming box any salt water which might otherwise contaminate it.

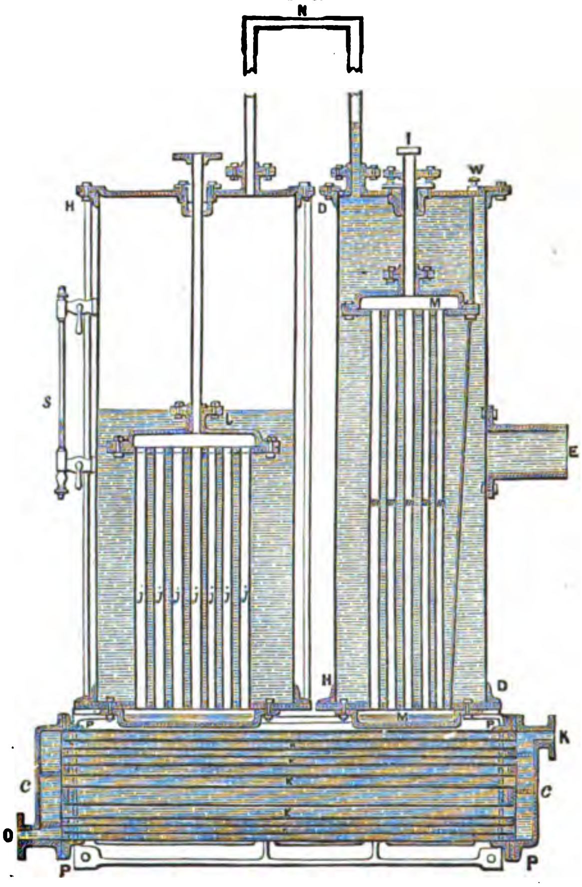
M, Fig. 2443. *m*, Fig. 2443.

N, air-pipe leading the air which separates from the sea water in the condenser D into the steam room or chamber of the evaporator H. This air-pipe must, of course, be considerably higher than the level of the sea water round the ship, or of the sea water in the turned-up pipe E, so that

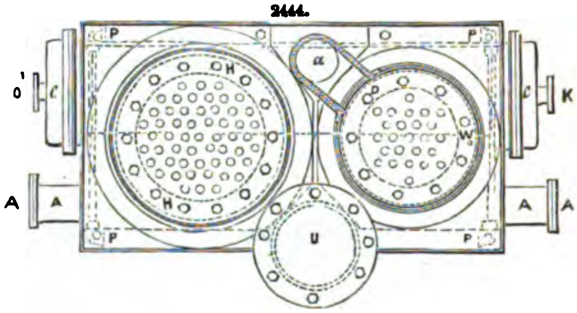
the salt water of the condenser may not, under any circumstances, be able to pass through it into the evaporator, which might be thus overfilled. This aëration is accomplished as follows;—

As the steam from the evaporator enters the pipes within the condenser at the top, through the pipe L′, it follows that the sea water at the top of the condenser D is brought, as we have already said under letter F, to a temperature which at the top reaches 206° or 208° Fahr.; this temperature gradually diminishes from the top downwards, so that at a zone corresponding to that of the exit-pipe E the temperature is reduced to about 140°. As the air contained naturally in water begins to separate therefrom at about 130°, it follows that the air contained in the condensing sea-water between E and the top of the condenser is separated; but when it has reached the top of the said condenser, it passes through the air-pipe N, and is carried by it to the evaporator H, where it mixes intimately with the secondary steam there produced by the evaporating pipes. This mixture of air and steam passes then through the pipes L and L′ into the tubes *m*, Fig. 2443, and the air is absorbed during the condensation of this secondary steam with which it was mixed, the condensed water so produced being thus super-aërated, and subsequently mixed through pipe Q, in the larger pipe R′, with the non-aërated water coming from the evaporator through pipe R. The mixed waters in traversing the refrigerator B are cooled down to the temperature of the sea water outside, and flow at O in the state of perfectly cold water, thoroughly aërated, but still retaining the bad taste and odour which always result from distillation, and of which it is deprived only after it has passed through the filter Y.

2443.



2444.



n, level to which the sea water is rising in the air-pipe. The height of this air-pipe must always be considerably greater than the level of the sea round the ship, or of the sea water in the turned-up pipe E, in order that there should not be any chance of the sea water passing into the evaporator through the said air-pipe.

O, exit-pipe, through which the mixed distilled waters, after being refrigerated, pass into the filter Y.

P, framing to which all the apparatus is bolted.

Q, exit-pipe for the condensed super-aërated water from the condenser D, which pipe is connected, like pipe R, with a larger tube R, in which it begins to mix with the condensed non-aërated water from the evaporator H.

R, exit-pipe for the condensed non-aërated water from the evaporator H, which pipe, after leading to and issuing from the steam-trap U, is connected, like pipe Q, with a larger tube R′, in which it begins to mix with the condensed aërated water from the condenser D.

R′, larger tube, in which the two kinds of fresh waters from the evaporator and from the condenser begin to mix.

S, water-gauge. T, air-cock of the steam-trap U.

U, steam-trap. It is a box containing a float provided with a plunger, acting in such a way that when the box contains only steam, or a quantity of condensed water insufficient to buoy the

float, the plunger closes the exit-pipe R; but as soon as condensed water has accumulated in the box in sufficient quantity to buoy up the float, the plunger of course no longer closes the exit-pipe R, and the condensed water may then escape as fast as it is produced.

V, cock admitting the condensed non-aërated water from the steam-trap U into the larger tube R'. This cock is ordinarily left open, and is used only in case the float of the steam-trap should become out of order, in which case the said float may be altogether removed by turning the steam off, and simply unbolting the cover, after which the escape of the condensed water is regulated by adjusting the cock so that nothing but the condensed water may flow out; this cock is also made use of for the purpose of cleaning the evaporator, Fig. 2443.

V', cock for cleaning the inside of the evaporating tubes, or for the purpose of obtaining fresh boiling hot water, which is done by shutting cock V, and opening cock V'.

W, breathing pipe, Fig. 2443. It is a pipe one end of which is in communication with the lower cap M of the condensing pipes *m*, and the other end is open to the atmosphere. The object of this pipe is not only to remove pressure from the cylinders, but likewise to afford an exit for the excess of air generated.

X X', two cocks placed between the condenser D and the larger tube R', for the purpose of obtaining hot fresh water, and likewise for the purpose of cleaning the condenser. This is done by cutting off the communication between the condenser D and the said larger tube R'; to do this, shut cock X, and open cock X'.

Y, filter for receiving the condensed water from both pipe R of the evaporator and pipe Q of the condenser, as they issue in a mixed and cold state from the refrigerator at O; the fresh water loses its empyreumatic odour in passing through the filter, and issues at *y* in the state of perfect fresh water, which cannot be distinguished by flavour from that of the very finest springs.

Z Z', two cocks placed between the refrigerator and the filter, for the purpose of cleaning the refrigerator, which is done by closing the communication between it and the filter; for this purpose shut Z and open Z'.

C, caps of the refrigerator already described, C, Fig. 2439, but shown in section, Fig. 2443.

D, condenser containing the sheaf of pipes *m*. surrounded by the sea water, which serves to condense the aërated steam from the evaporator H, and to produce the air wherewith that steam is aërated.

H, evaporator. It is a cylinder into which the sea water is allowed to rise so as to cover the upper cap J of the evaporating pipes *j* in that cylinder, and no more, the level being kept at that height either by a self-acting float, or by manipulation, as was said in describing G, Fig. 2443.

I, steam-pipe from a boiler. This steam-pipe brings steam more or less under pressure from any description of boiler; it passes through a stuffing box, reserved in the cover of H, and is connected to the upper evaporating cap J of the evaporating tubes *j*.

J, cap covering the sheath of tubes *j j*, in which the steam from the boiler diffuses itself, and is condensed by giving off its latent heat to the sea water round the said evaporating tubes; after which it flows as distilled, but non-aërated, water to the inlet K, in one of the caps C of the refrigerator B. It must here be observed that, although the sea water in H H is at a boiling temperature after the first few minutes of the apparatus being put into action, yet it will condense the steam in the tubes *j j j*, because that steam, being under pressure, is necessarily of a higher temperature than the water in H H, which is not under pressure. Thus, whilst the pressure-steam in the tubes *j j j* is condensed, non-pressure steam is generated from the water in H H outside of them. This latter or secondary steam passes through the tube L L' to the upper cap M of the tubes *m m m* in the aërating cylinder D D, where it also is condensed, and passes through the lower cap M and a pipe Q, Fig. 2439, to the inlet K, mixing at once with the distilled water from the boiler through the tube R', already described.

k, sheaf of pipes of the refrigerator B, for the purpose of cooling the condensed water. This has already been described in B and C, Fig. 2439.

M, caps covering the end of the sheaf of tubes placed in the condenser D. See the explanation given at letter D, Fig. 2439.

m, sheaf of pipes placed between the two caps M, for the purpose of condensing the aërated steam from the evaporator H.

W, breathing pipe, one end of which communicates with the lower cap M of the condenser, while the other end is open to the atmosphere. This pipe serves to remove pressure from the cylinders, and for the exit of the excess of air. When water or steam issues through that pipe, it is a proof either that too much steam is sent in, or that it is at too great a pressure.

Instructions for Working the Apparatus.—The first thing to be done is to charge the apparatus with water. This is done by establishing a communication between the external sea water and the apparatus. If the latter is placed below the level of the sea, this is easily done by turning on the cocks of the large tubes A and E, and the cock F of the feed-pipe, whereupon the salt water fills both the refrigerator B and the condenser D to a certain distance *n* of the air-pipe corresponding with the level of the sea. It then passes through the feed-cock F, thence through the feed-box G, down through the pipe G', into the evaporator H, up to a line standing at about the middle of the glass gauge S, where it is maintained at a uniform level by the float within the feed-box G; the float being then buoyed up, closes, by means of the valve attached to it, the aperture of the feed-pipe F, immediately above the float, whereby all further supply of salt water is shut off. until such time as by subsequent evaporation, or discharge of the brine in the evaporator, the level of the water in the evaporator H, and consequently in the feed-box G, will have been lowered, whereupon the float in G, sinking, will allow a fresh quantity of salt water to flow in until the proper level is restored. The feed-cock F should always be left wide open, except on an emergency; that is to say, except the valve or the float in the priming and feed box G should become damaged or out of order, in which case the supply of salt water to the apparatus would have to be regulated by hand with that cock.

The apparatus being charged with salt water, as just said, the boiler being ready to furnish the necessary steam, and admitting, of course, that the steam-pipe I is in communication with the said boiler, the next thing to be done is to open the steam-cock of that pipe, I, and at the same time shutting cock Z, and opening cock Z', at the extremity of the refrigerator, and opening likewise entirely at first the cock T of the steam-trap U. On opening this small cock T of the steam-trap U, nothing but air will at first rush out, but as soon as steam issues from it, it should be *almost* closed, leaving only room for the *smallest possible* wreath of steam slowly to issue from it. As soon as the steam-cock of pipe I is open, the steam will rush through that pipe into the sheaf of pipes of the evaporator, in which it will be condensed by the salt water which surrounds them, and flow in the state of condensed non-aërated water through the pipe R, through the steam-trap U, through the continuation of pipe R, and out through cock Z'. If the apparatus has been left without working for some time, the condensed water issuing at cock Z' will have a rusty colour, wherefore it should be left running until it flows out clear at Z', in order not to foul the filter, which would be the case if that rusty water were allowed to flow into it. As soon, however, as the condensed water flows out in a clear state at Z', shut off this cock Z', and open cock Z, so that it may pass into the filter.

But the heat of the steam in the sheaf of pipes *j*, within the evaporator, soon brings the sea water round them to the boiling-point, and converts it into steam. As soon, therefore, as the sea water in the evaporator begins to boil, which may be known by a slight motion of the water in the water-gauge S, or by the pipes L and L' of the feed and priming box G, and, of course, this box itself becoming hot, open the feed-cock of pipe F full (unless, of course, the float in the box G should be out of order, in which case the cock of the feed-pipe F must be regulated so as to supply water to the proper level in the condenser, which is indicated by the glass gauge S), shut the cock X of pipe Q at the top of the condenser, and open the cock X' of that same pipe; whereupon the secondary steam from the evaporator passes through pipe L, through the priming box G, in which any salt water with which the said steam may be mixed is deposited and returned through pipe G' to the evaporator whence it came, while the pure steam continues its course through pipe L' into the sheaf of pipes *m* immersed in the salt water contained in the condenser D, and being condensed in the said pipes, flows out, in the state of aërated fresh water, through the cock X', as long as it has a rusty colour, which will be only for about a minute. As soon as the water flows out clear and sweet from that cock X', shut the latter and open cock X, so that the super-aërated fresh water may now mix with the non-aërated fresh water in pipe R', and flow with it through the refrigerator, and thence into the filter, the whole issuing then from the filter in the state of *perfect* fresh water. If the apparatus be placed on deck, or on land—that is to say, above the natural level of the sea—it may be charged either by working the pump or by pouring water into the turned-up pipe E until the glass gauge indicates that the proper quantity of water has been introduced. The subsequent pumping must be regulated so that the condenser D remains hot down to E, and cold from E downwards. When the evaporator begins to give off steam, open also the brine-cock *i*, but only to such an extent as to permit a quantity of brine to be *constantly* flowing out, equal to about one-fourth part of the whole of the fresh water produced.

Attention to this is absolutely necessary for if too much brine be allowed to run out, the apparatus will not produce its proper quantity of fresh water; for since every portion of brine which flows out is replaced by a corresponding quantity of new sea-water through the feed-cock F, feed-box G, and pipe G', it is clear that the proportion of new sea-water thus admitted into the evaporator G by an extravagant outflow of brine might be so considerable as actually to stop all evaporation in the evaporator. On the other hand, if the brine-cock be not sufficiently open, the flow of brine being less than is proper, the sea water in the evaporator would eventually become so concentrated that a deposit or incrustation of salt would be formed. If, however, the operator take care to adjust the brine-cock so that the flow of the brine is at the rate indicated (about one-fourth of the whole fresh water produced), there will be no chance of stopping the evaporation, nor danger of incrustation.

When the operator wishes to discontinue the distillation, all he has to do is to turn off the steam from the boiler, and to shut both the brine-cock *i* and feed-cock F.

To Work the Apparatus.—1st. Open the steam-cock from the boiler to pipe I.

2nd. Open the cock Z', and shut the cock Z of the refrigerator, and as soon as the condensed water flows clear and sweet from pipe Z', shut the latter, and open Z, that the clear fresh water may flow into the filter.

3rd. As soon as steam begins to be given off by the evaporator, which is known by pipes L and L and the feed-box G becoming hot, open the feed-cock of pipe F and the cock X', shutting at the same time X, and as soon as the fresh water flows clear and sweet at X', shut the latter and open X, so that the clear fresh water may flow through the refrigerator and thence into the filter.

4th. Open the brine-cock *i*, so as to let the brine flow out in the proportion of about one-fourth part of the whole of the fresh water produced.

To Stop the Working of the Apparatus.—Shut off the steam-cock I. Shut off the brine-cock *i*. Shut off the feed-cock F.

Special Instructions.—Look occasionally at the water-gauge, in order to see that the proper level is kept up in the evaporator. If it be observed that the level is too low in the glass, the feed-cock being open all the time, it is a sign that too much steam has been turned in from the boiler, and therefore the steam-cock from the boiler to pipe I should be less open.

Look occasionally at the brine-cock *i*, to see that it is discharging the proper quantity of brine. It will be advisable also now and then to open the said brine-cock full for a few seconds, in order to discharge any rusty or muddy deposit which might otherwise stop it; and for this reason, once every month or so, it should be left quite open, in order to empty the evaporator completely, so that any rust or deposit may be expelled. Of course, when the brine-cock is full open for the purpose of emptying the evaporator, the feed-cock F should be kept closed.

The operator will perceive that a piece of vulcanized india-rubber *g* contains a metallic rod

inside, which metallic rod is connected with the float in the feed-box G. The use of this india-rubber tube is to enable him, by grasping the said rod through the india-rubber tube, to move the float up and down in the said feed-box, should he wish at any time to ascertain that it (and the valve attached to it) is acting properly. Should it become necessary to remove the float, it is easily done by unbolting the cover of the feed-box G, and the flanges of the feed-cock F, connected therewith. The apparatus may then be worked without the float by replacing the cover and regulating by hand the flow of sea water through the feed-pipe F.

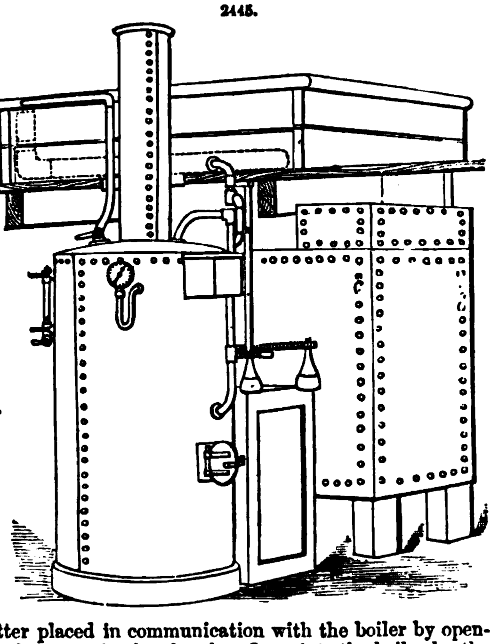
The feed-cock F should be left full open when at work, since the supply of the sea water to the evaporator is perfectly regulated by the float ball and valve in the box G; it is only in case of emergency—that is to say, in case of the valve leaking or getting out of order from some accidental obstruction or otherwise—that the supply of water to the evaporator may be regulated by hand with the said cock until such time as will permit the operator to remove such obstruction, should any, peradventure take place. The feed-cock is therefore put there merely as an extra measure of precaution.

The small cock T of the steam-trap U should be left very slightly open, so that an exceedingly small wreath of steam may be seen issuing from it. This is for the purpose of letting out any air which might otherwise accumulate therein and interfere with the proper action of the float in the said steam-trap. It may also be open for a few seconds now and then—say two or three times a day—in order to see that it is clear.

If water should rush out in any quantity on opening the small cock T of the steam-trap U, it is a sign that the float is waterlogged or otherwise out of order; the remedy is to examine and repair it if wanted, or if possible, and if not, to remove it altogether, and regulate by means of the cock V of pipe R, so that as little steam as possible should pass through it, and so that only the water condensed in the evaporator may flow out. If, in case it has been found necessary to remove the float of the steam-trap, the condensed water should accumulate in the said steam-trap, which is known by opening the cock T in the cover thereof (in which case water instead of steam will rush out from the said cock T), it will be sufficient to open the cock V of pipe R for a few moments, whereupon the accumulated condensed water will pass into the refrigerator. In fact, the apparatus can work very well without the float in the priming box G, and without the float in the steam-trap U, either or both; but with them the apparatus works automatically, and without them the operator has to see that the feed-cock F is open only to the proper degree, or he must keep it shut altogether, and open it from time to time, so as to feed intermittently—say every half hour—to admit a new quantity of sea water into the evaporator. For emptying completely the condenser and refrigerator, unbolt the flange at either end of A. The evaporator may, of course, be completely emptied by opening the brine-cock *i* full.

Chaplin's Apparatus.—A distilling apparatus constructed by Alexander Chaplin, of Glasgow, for obtaining a supply of pure, fresh, aërated water from sea water, or from other water containing impurities, is shown in Fig. 2445. The apparatus, which is of simple construction, is almost self-acting, and is adapted for use either on shipboard or on shore. It consists of a boiler, from which a steam-pipe is led to a coil of pipes placed in a shallow wooden tank, which is kept filled with salt water, the boiler being fed from the tank by feed arrangement. The steam from the steam-pipe of the boiler is discharged into the condensing tubes in the form of a jet, an opening being left around the jet nozzle, through which air is drawn in by the action of the steam. This arrangement, by mixing the steam with air, is found to effectually aërate the distilled water. The distilled water in the condensing coils runs down, as it is formed, into a filter, and thence into a store tank below.

2445.



The feed apparatus, which is arranged on a well-known plan, consists merely of a chamber communicating at the top and bottom with the boiler, by means of pipes furnished with cocks, and also connected by another pipe, provided with a cock, with the tank containing the water employed for effecting condensation. In order to feed the boiler, the communications between the latter and the feed-chamber are closed, and the latter is then filled with water from the tank, this water being, of course, more or less heated by the steam in the coils of pipes. The communication between the tank and chamber is then closed, and the latter placed in communication with the boiler by opening the cocks on the connecting pipes, when the water in the chamber flows into the boiler by the action of gravity.

The method of working this apparatus is as follows;—The tank or condenser should be filled by the hand-pump with sea or other water, and the boiler should be also filled up to half-glass, the water supply being afterwards regulated by the feed apparatus. The fire in the boiler may then

be lighted. Coal, wood, peat, or mineral-oil fuel may be used, the latter being preferred when it is desired to make the apparatus as nearly as possible self-acting. In this case a special combustion cone is provided, the oil flowing over this cone, which must be first heated, so that the oil will ignite upon it. Combustion is then forced by the passage of air upwards through numerous small holes formed in the cone, and the flames are thus thrown against the sides of the fire-box. The steam being got up to, say 5-lb. pressure to the square inch, the main steam-pipe may be opened into the aërating pipe or cup, and thus a mixture of steam and air will be discharged into the condenser. The water in the tank becomes heated before it passes into the steam-boiler, and the whole of the sea water pumped up to the tank is gradually evaporated and converted into fresh aërated water fit for use, except a small portion lost by waste and in blowing off the boiler to prevent the incrustation of salt.

DIVIDING MACHINE. Fr., *Machine à diviser;* Ger., *Theilmaschine;* Ital., *Macchina da dividere;* Span., *Máquina de dividir.*

See Hand-Tools. Machine-Tools.

DIVING. Fr., *Plonger:* Ger. *Tauchen;* Ital., *Lavoro da marangoni;* Span., *Buceo.*

Before men are detailed for diving, they should be examined as to their fitness by a medical officer. If this be impracticable, it is useful to know that men coming under any of the following classifications should not be employed:—

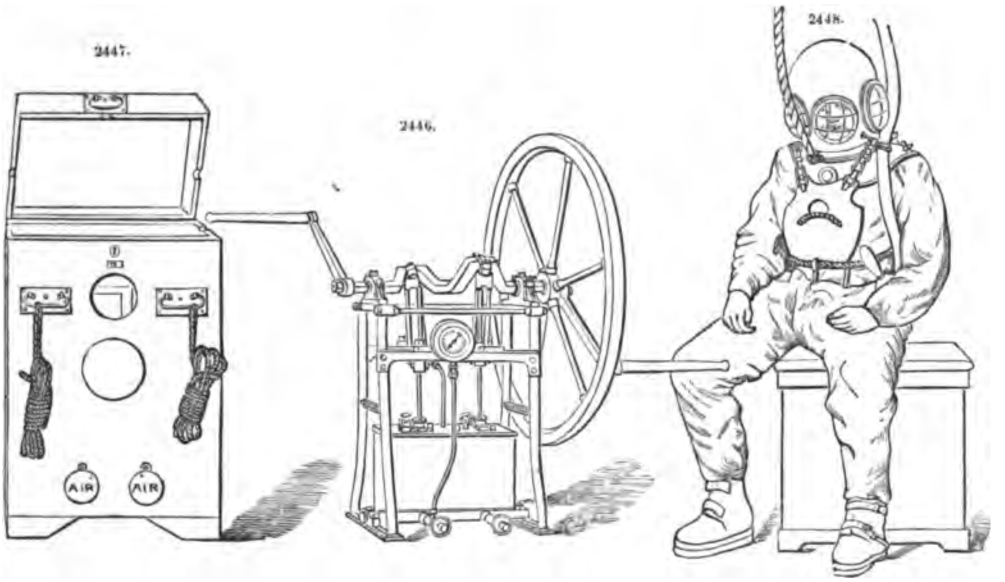
1. Men with short necks, full blooded, and florid complexioned.
2. Men who suffer much from headache, are slightly deaf, or have recently had a running from the ear.
3. Men who have at any time spat or coughed up blood.
4. Men who have been subject to palpitation of the heart.
5. Men who are very pale, whose lips are more blue than red; who are subject to cold hands and feet; men who have what is commonly called a languid circulation.
6. Men who have bloodshot eyes and a high colour on the cheeks, caused by the interlacement of numerous small but distinct blood-vessels.
7. Men who are hard drinkers and who have suffered severely and repeatedly from venereal, or who have had rheumatism or sunstroke.

The *air-pump* employed until lately was a three-throw force-pump, but in 1868 a double-action two-cylinder pump was tried and found to answer well; its sole advantage over the other is that it can supply air to two divers working independently, at different levels, each diver being in direct connection with one of the cylinders. When work has to be carried on in water upwards of 90 ft. deep, only one diver should be supplied with air from the pumps. The pump, Fig. 2446, is securely fitted into a strong wooden case, Fig. 2447, and is worked by means of two winch-handles

2447.

2446.

2448.



and a fly-wheel. These latter are taken off for transport, when the ends of the crank-axle are protected by *nipples* screwed on to the pump-case. Inside the pump-case is a box for small stores. The pumps are capable of compressing air up to 240 lbs. on the square inch, and are provided with a pressure-gauge, the dial-indicator of which shows the depth and the corresponding pressure; the cylinders are kept cool by water in a copper cistern round them. Before the pump is moved about after use, the water from the cistern should be drawn off by unscrewing the nut under the plate marked water. Olive oil must be used for the pistons, admitting it by means of the small cock in the cylinder cover. When putting the pump together, the different parts must be arranged according to their marks. The bottom valves can be examined by unscrewing the plate at the bottom of the case, and the top ones by unscrewing the cylinder cover, taking it off with the piston. If the

pump works heavily after lying by, warm water poured into the copper vessel round the cylinders will soften the oil round the pistons and make them work easily.

The *air-pipes* are in lengths of 45 ft., and are made either of india-rubber covered with canvas with a copper spiral wire inside, or else of vulcanized india-rubber with a galvanized iron spiral wire. As the former requires a long time to dry, the latter is probably the best for general purposes. The internal diameter of the pipes is $\frac{5}{8}$ of an inch, and they are fitted together by means of gun-metal union joints. If two men are to be supplied with air from one pump, the necessary length of air-pipe must be fitted to the nozzle of the air-delivery pipe of each cylinder. If only one man is to go down, the air-delivery pipes of the two cylinders must be connected by the *double connection*, and the air-pipe screwed on to its nozzle.

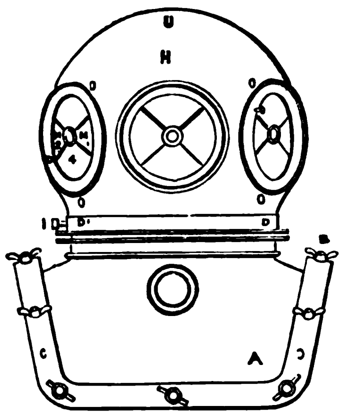
The *diving dress* is made of solid sheet india-rubber, covered on both sides with canvas; it has a double collar, the inner one to pull up round the neck, and the outer one of vulcanized india-rubber to go over the breast-plate and form a water-tight joint. The cuffs are also of vulcanized india-rubber, and fit tightly round the wrists, making, when secured by the wristbands, a water-tight joint, and at the same time leaving the diver's hands free.

The *wristbands* are of vulcanized india-rubber, with tape at their ends.

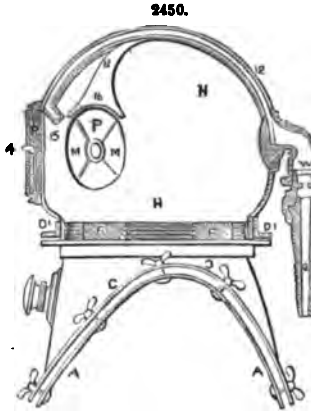
The *breast-plate* made of tinned copper has a valve V, Figs. 2450, 2451, in front, by which the diver can regulate the pressure of air inside his dress and helmet. When the handle of the valve-cock is vertical the valve is shut, when it is across the breast-plate the valve is open. The outer edge B of the breast-plate is of brass, and has twelve screws B, C, securely fitted to it at intervals, and projecting upwards, which pass through corresponding holes in the outer collar C of the dress, and upon which the four pieces of the *breast-plate band* are secured by thumb-screws. The neck of the breast-plate is fitted with a segmental screw bayonet joint. The breast-plate has two studs in front, to which the front and back weights are attached.

The *helmet*, Figs. 2449 to 2451, of tinned copper, has a segmental bayonet screw F, F, F, at the neck, corresponding to that of the breast-plate A, which enables the helmet to be removed from the

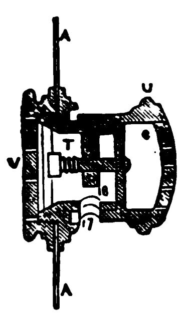
2449.



2450.



451.



breast-plate by $\frac{1}{8}$ of a turn. It has three bull's-eyes of plate glass M, M, at the front and sides, protected by brass guards P; the front bull's-eye can be unscrewed. An outlet-valve is provided at the back of the helmet which is beyond the diver's control. An elbow-tube W is securely fitted on to the helmet, to which the air-pipe Q is attached; in this tube is a valve W opening inwards, so that the air can enter, but in case of a break in the air-pipe cannot escape. There is a brass stud on each side of the helmet, that on the left to attach the air-pipe to, and that on the right for the life-line, Fig. 2448.

The *front* and *back weights* are of lead, heart-shaped, and weigh about 40 lbs. each; they have gun-metal clips to fasten on to the studs on the breast-plate, and the back weight has a lashing attached to it, Fig. 2448.

The *boots* are of stout leather with leaden soles, and are secured over the instep by a couple of buckles and straps; each boot should weigh at least 15 lbs.

The *iron ladder* is provided with stays to bear against the side of the boat from which the diving is carried on, but a 6-ft. length of scaling ladder will answer the purpose. Rope ladders wider than the ordinary miner's rope ladder, are provided: they have thimbles at each end, so as to be more readily attached to the bottom of the iron ladder and to the ladder-weights; the *ladder-weights* are merely 56-lb. weights, provided with movable handles of round iron, which are passed through the thimbles at the ends of the rope ladders and secured by linch-pins.

The *crinoline* should be used in deep water, and at any time at the diver's option; it is placed round the body and tied in front of the stomach, being supported by the braces. it affords protection to the stomach and enables him to breathe more freely.

The *cuff-expanders* are of galvanized iron, and are intended to enable the diver's hands to be got in and out of the cuffs; the scoop part of each should be placed inside the cuff, and the cuff opened by drawing the handles apart.

The ladder having been fixed, the position of the pump should be decided on, and it should be securely lashed by means of the ropes attached to the handles down to the stage into which the

screw-eyes M, M, Fig. 2450, should be fastened if necessary; the pump should be placed out of the way of the divers and clear of the men attending on them, and of all the men employed The best position for the pump is facing the head of the ladder, and about 6 ft. from it, over the centre row of barrels, if the diving be carried on from a raft.

While the diver is dressing, the pump should be prepared for use, the winch-handles should be taken out of the pump-case, the nipples protecting the crank-axles removed, the nuts being replaced on their screws. The nuts for the ends of the crank-axles are taken off, the fly-wheel placed on the long arm, and the winch-handles put on and secured by the nuts which are screwed home with the spanner. The pump is always worked in its case.

The flap covering the pressure-gauge and that at the back of the pump-case should be opened, the screw on the overflow-nozzle of the cistern removed, and the cistern filled with water; the caps of the air-delivery pipes should be removed, the necessary lengths of air-pipe should be put together carefully with washers in place, and all the screws must be worked home by means of the *two* double-ended spanners. The air-pipes should be tested by holding the palm of the hand to the end of the pipe, till the pressure shown on the pressure-gauge is considerably above that corresponding to the depth the diver is to descend.

The diver having taken off his own clothes, puts on a guernsey, a pair of drawers very carefully adjusted outside the guernsey, and securely fastened by the tape round the waist to prevent them from slipping down, and then a pair of inside stockings. If the water be cold, the diver may put on two or more of each of the above articles. He then puts on the crinoline and woollen cap, drawing the latter well over his ears; some divers find relief from putting cotton saturated with oil in their ears.

The *shoulder pad* is then put on and tied under the diver's arms. He then gets into the diving dress, which in cold weather should be slightly warmed, drawing it well up to his waist. he next puts his arms into the sleeves, an assistant opening the cuffs by means of the cuff-expanders, or by inserting the first and second fingers of both hands, taking care to keep his fingers straight. The diver by pushing forces his hand through the cuff. He puts on a pair of outside stockings and a canvas overall to preserve the dress from injury.

The diver then sits down, and the inner collar of the dress is drawn well up and tied round the neck with a piece of spun yarn, and the breast-plate put on, great care being taken that the india-rubber of the outer collar is not torn in putting it over the projecting screws of the breast-plate. The four pieces of the breast-plate band, which with the thumb-screws had been previously placed for safety in one of the boots, are then put over the outer collar, and secured to the projecting screws by means of the thumb-screws; the centre screw of each plate should be tightened first. It will generally be sufficient if the thumb-screw be screwed up hand-tight, the spanner being only used when necessary. The canvas overall is now adjusted and the boots are put on.

The wristbands are passed tightly several times round the cuffs and their tape ends tied, and the sleeves of the overall are drawn down to cover them. If gloves are to be used, the wristbands will be put on over them as well as the cuffs. The helmet (without the front bull's-eye) is then put on; a loop of the life-line is placed round the diver's waist, the line brought up in front of the man's body, and secured with a piece of small rope passing round his neck, or to the stud on the helmet. The waist-belt is buckled on with the knife on the left side, the end of the air-pipe being passed from the front, through the ring on the belt on the man's left, and up to the inlet-valve on the helmet to which it is secured; the upper part of the pipe is then made fast by a lashing to the stud on the left of the helmet. The diver then steps on the ladder, and two men are told off to *man the pump*.

The weights are then put on, the back weight first, the clips being placed over the studs on the breast-plate, and the clip-lashings over the hooks on the helmet. The front weight is then put on, and the two are secured to the diver's body by means of the lashing from the back weight, which is passed round the waist, through the thimble beneath the front weight, and tied to the other end of the lashing at the back weight, Fig. 2448.

When the signalman is sure that all is right, and that the diver understands all the signals, he gives the word *Pump* and screws the centre bull's-eye into the helmet securely; this done, he takes hold of the life-line and pats the top of the helmet, which is the signal for the diver to descend.

With inexperienced men, it is advisable to have a rope ladder down to the bottom, but an expert diver prefers simply a rope; they both must be weighted at the bottom.

Each diver while under water requires a signalman to hold his life-line, and an assistant to hold his air-pipe, both of which should be kept just taut, clear of the gunwale, so that any movement of the diver may be felt. While the diver is under water no talking or laughing is to be permitted.

The diver should descend slowly, halting for a few minutes after his head is under water, to satisfy himself that everything is correct, and then continue the descent: if he feels oppressed or experiences any humming noise in his ear, he should rise a yard or two, and swallow his saliva several times; he must not continue to descend unless he feels comfortable. If oppression, singing in the ears, or headache continue, he must not persevere, but return slowly to the surface. To dive to great depths, such as 100 or 150 ft., requires men of great practice, and able to sustain the consequent enormous pressure.

On arriving at the bottom, the diver will give one pull on the life-line to notify that he is all right. In returning from great depths the diver should ascend very slowly, and thus avoid the effects of passing too abruptly from considerable pressure to that of the open air; if he stops now and then he gets gradually and regularly accustomed to the change. The ascent from a depth of 20 fathoms should occupy from 20 to 40 minutes. It is more important to move slowly in rising than in descending.

The diver takes down with him the ladder-line, which he secures to the foot of the ladder or rope by which he has descended; this line should be coiled up in his hand with a loop round his wrist, and as he leaves the ladder he lets the line gradually uncoil. so that if he be at any distance

off he can find his way back to the ladder when he wants to return. While at the bottom he should never let go the ladder-line if by any accident he does so and cannot find the ladder, he must make the signal to be hauled up.

The diver should generally walk backwards; if he meets anything he must turn round and feel this precaution is necessary, as by running against iron spikes, &c., the bull's-eyes may be broken; he must return to the ladder by the way he came, otherwise he may get his pipe or life line entangled

When two divers are down they must be careful not to cross each other's paths, and thus get their life-lines and air-pipes foul

The signalman is the responsible person, and must be very vigilant all the time the diver is down; occasionally he will give one pull on the life-line, and the diver should return the signal by one pull signifying all right; if the signal be not returned the diver must be hauled up, but if the diver wishes to work without being interrupted by signal, he gives one pull on the line, independently, for all right, let me alone. If the signalman feels any irregular jerks, such as might be occasioned by the diver falling into a hole, he should signal to know if he is all right, and if he does not receive any reply, he should haul him up immediately. If the diver from any cause is unable to ascend the ladder and wishes to be pulled up, he gives four sharp pulls on the life-line. If while being hauled up the diver gives one pull it signifies all right, don't haul me any more. The diver should be hauled up slowly and steadily If the signalman wishes the diver to come to the surface, he gives four sharp pulls on the line, on which the diver should answer all right, return to the foot of the ladder, and signal to be hauled up.

One pull on the air-pipe signifies that the diver wants more air. *Two* pulls on the life-line and *two* pulls on the air-pipe in rapid succession, signify that the diver is foul and cannot release himself and requires the help of another diver on receiving such a signal no attempt should be made to haul the diver to the surface.

The above signals are to be invariably used by the Royal Engineers: other signals may be arranged as is most convenient for any particular work, as a great variety can be made with the life-line and air-pipe. The diver can communicate with the surface by means of a slate.

When the diver comes up, the front bull's-eye should be removed immediately he gets to the surface; if he is going down again within a quarter of an hour, he can have the wristbands removed, the weight taken off his body, by leaning forward, and resting the front weight on the gunwale. if he is to cease work the front and back weights must be removed before he leaves the ladder; it is advisable to detach the air-pipe from the helmet next. The diver must then be assisted into the boat, the attendants lifting his legs in one after the other. He can then sit down and have the helmet removed, also the waist-belt, life-line, and boots; next the overall and the outside stockings. The breast-plate band should then be removed, the thumb-screws at the junctions of the breast-plate bands being unscrewed first. The bands being removed, the outer collar should be taken off with care so as not to tear it in getting it over the screws. The breast-plate is then removed, the dress pulled down, the cuff-expanders or fingers being used to enable the diver to withdraw his hands from the cuffs The shoulder pad and crinoline and other clothes can then be taken off.

After the day's work is over the joints of the air-pipes must be carefully cleaned, and the pipes coiled away in the helmet-chest The diving dress should be cleaned, and if wet inside turned inside out and hung up in the shade to dry; the dresses if used in salt water should be washed at least once a week in clean fresh water. The under-clothing must be kept dry and aired.

When in store, the pump, &c., must be kept clean and free from verdigris, the clothing occasionally aired, the tools oiled, &c. When wanted for use after lying by for some time, the pump should be taken to pieces by a good fitter, and examined to see that it is in proper working order. The helmet-valves should be unscrewed and examined to see that the valve is free from verdigris, but slightly greased with tallow to prevent leakage; the spring should be good, of greater or less strength according to the depth of water. All the screws of the helmet, breast-plate, air-pipes, &c., must be kept free from verdigris and clean, but wiped with an oily rag. When a piston works loose, the screw at the top must be turned a little with a spanner.

The number of men required for a diving party is,—

	With two divers down.	With one diver down
In charge	1	1
For life-lines	2	1
For air-pipes	2	1
For pumps	2	2
Divers	2	1
1 non-commissioned officer and	8	1 and 5

The above is exclusive of men to haul up, &c., according to the nature of the work being carried on.

For instruction, a class may consist of from five to ten men.

If the diving is simply for the recovery of a lost article, the raft should be moored up stream about 10 or 15 ft. from the supposed place of the article; a weight with a ladder-line attached should be sunk about 10 or 15 ft. down stream from the place; the diver should take the other end of this ladder-line down with him, and when at the bottom haul it taut and fasten it to his ladder. He then uses the ladder-line as a guide, and searches the ground on both sides of it if unsuccessful he shifts the position of the weight, keeping the ladder-line taut all the time, and so continues.

An equipment consists of the following packages taken from T. L. Gallwey's Instructions in Military Engineering:—

Description of Articles.	Weight of each.				Total Weight.			
	cwt.	qrs.	lbs.	oz.	cwt.	qrs.	lbs.	oz.
1 pump, in case, complete	2	3	17	0	2	3	17	0
1 fly-wheel	0	3	24	14¾	0	3	24	14¾
1 box, for oil, &c.	0	3	9	0	0	3	9	0
1 iron ladder	0	2	20	0	0	2	20	0
5 rope ladders	0	1	8	0	1	2	12	0
2 hand-over-hand ropes	0	0	21	0	0	1	14	0
2 coils 1-in. and 2-in. rope, spare ..	0	3	3	0	1	2	6	0
2 ladder-weights	0	2	0	0	1	0	0	0
2 clothes-chests, complete	1	3	26	6½	3	3	24	13
2 helmet-chests, complete	1	2	23	15¼	3	1	19	14½
Total	10	3	13	4½	17	1	1	10¼

The contents of the several chests are given below:—

Names of Stores.	No.
Case, pump, with lock and key	1
Containing—	
Gauge, pressure, fixed to pump-case ..	1
Lashings, spliced to handles, each 8 ft. ..	4
Pump, air, diving, fixed to pump-case ..	1
Cramp, screw, for fly-wheel	1
Handles, winch, for pump	2
Nipples, crank, fixed to case for transport	2
Spanner, box, for nuts in pump-case ..	1
Can, oil, feeding	1
Box, wood, for small stores, fitted into pump-case	1
Containing—	
Cap, brass, for air-delivery pipe (spare)	1
Connection, double, for use with a single diver	1
Gimlet, spike, ⅜-in	1
Joints, union, double, 1 male and 1 female	2
„ „ single, „ „	4
Nozzle, overflow (gun-metal)	1
Nut for securing pump-handles (spare)	1
Screw-drivers, 1 6-in. and 1 2½-in. ..	2
Screw-eyes, for securing pump-case to stage	4
Spanners, double-ended	3
„ M'Mahon's, 9-in.	1
Washer-cutter, for washers of air-pipes	1
Box, tin, for valves, &c.	1
Containing—	
Valve, piston (spare)	1
Valves, bottom, spring (spare)	2
Washers, leather, for joints of air-pipes (spare)	24
Wheel, fly, for pump	1
Box, oil, with lock and key	1
Containing—	
Cotton, waste .. .. lbs.	6
Oil, olive, best, for pumps, in tin can, gals.	3
Oil, neats-foot, for leather „ „	3
Ladder, iron	1
„ rope, diving 20-ft. .. .. pieces	5
Weights, ladder, 56-lb.	2
Chest, clothes, with lock and key	1
Containing—	
Belt, waist, for knife	1
Boots, diving, with leaden soles .. pair	1

Names of Stores.	No.
Drawers, woollen .. .. pairs	4
Dresses, waterproof diving	2
Expanders, cuff	2
Gloves, waterproof .. .. pair	1
Guernseys	4
Instructions, printed	3
Knives, diving	2
Line, ladder, 1-in. rope .. .. 60 ft.	1
Lines, life, 2-in rope .. .. .. „	3
Overall, canvas	1
Sheath for spare knife	1
Stockings, outside, grey .. .. pairs	2
Weight, lead, front	1
„ „ back, with lashing attached	1
Wristbands, 4 on dresses and 4 spare pairs	8
Materials—	
Canvas, prepared, for repairing diving dresses .. .. yards	3
Composition for dresses .. in lb. tins	2
Chest, helmet, padded at the bottom, with lock and key	1
Containing—	
Bull's-eye, front, frame and glass complete (spare)	1
Caps, woollen	2
Crinoline	1
Glasses for bull's-eye, front (spare)	2
„ „ oval (spare)	2
Helmet and breast-plate complete, with breast-plate band (in 4 pieces), 12 thumb-screws, and front bull's-eye ..	1
Pads for helmet	2
Pipes, air, spiral wire, with union joints, in lengths of 45 ft.	3
Stockings, inside, white .. .. pairs	4
Box, tin, for helmet stores	1
Containing—	
Screws, for breast-plate	6
Spanner „ screws	1
„ nuts of oval eye-glass ..	1
Springs, inlet, small, for helmet (spare)	2
„ outlet, large „ „	3
Thumb-screws for breast-plate „	12
Washer, leather, for bull's-eye „	1
„ „ neck ring „	1

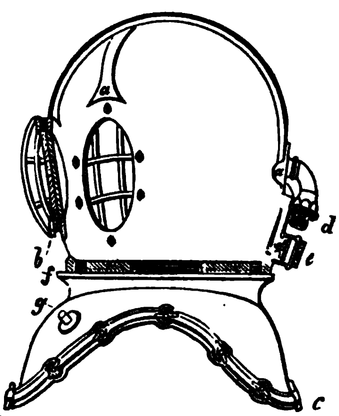
See J. W. Heinke, On Diving Dresses and Apparatus for Working under Water, Trans. Inst. C. E., 1856.

About the year 1825, C. A. Deane took out a patent for an apparatus to recover property from houses on fire As this did not meet with support from the fire-insurance offices, C. A. Deane turned his attention to diving; and, in conjunction with his brother, J. Deane, tried some experiments on the Croydon Canal, with a canvas helmet and an ordinary pair of forge-bellows. These experiments proved so far successful as to satisfy them that diving was practicable, with proper

means to supply the diver with air. Accordingly they had an air-pump and helmet constructed, but as they did not fully answer the purpose, Messrs. Deane applied to A. Siebe, who, in 1830, made others, which proved satisfactory. The helmet was what was termed an open one. The air entered by an elbow at the back, and was conducted, by means of the tube *a*, Fig. 2452, to the diver's face, so that he at once inhaled the fresh air, and at the same time the breath was prevented from condensing on the glasses. The foul air escaped from underneath the jacket attached to the helmet, on the same principle as the air escaped from a diving bell.

With this apparatus, Messrs. Deane undertook and executed several important diving operations. Amongst other experiments that were tried was the introduction, in 1832, of a valve in the front of the collar of the helmet, by which the diver could regulate the exit of the foul air at pleasure. When the valve was closed the air was retained, the dress expanded, and the diver rose to the surface. After several careful trials, Messrs. Deane came, however, to the conclusion that the diver was safer with the air-pipe and signal-line in the care of an attendant, who could haul him up at a moment's notice; since, with the valve above alluded to, the diver was liable to get hurt by rising up under the vessel or boat, or by becoming entangled with the rigging of the wreck, or portions of the works upon which the operations were conducted. For these reasons the use of the valve was discontinued.

2452.



As diving came into more general use, several accidents happened through inexperienced divers not keeping themselves in a proper position when using the open helmet. In consequence of this, A. Siebe, in 1837, introduced the close helmet, and at the same time G. Edwards proposed one nearly similar. Although personally acquainted with each other, it was not until both had perfected the idea that they found they had been working to attain the same object. It must not be forgotten that divers owe much to the skill and ingenuity of Samson Barnett.

The close helmet, as represented in Fig. 2452, consisted of a front glass *b*, which could be unscrewed to enable the diver to take refreshment, or to give orders, without removing any other portion of the dress. The dress was fastened to the helmet by means of the flanges *c*, pressed together by screws and *wing-nuts*. The air entered at the back, as in an open helmet. There was an entrance-valve *d* screwed on the elbow; this allowed the air to enter the helmet, but prevented its return. If the pipe should burst the diver had plenty of time to come to the surface. The outlet-valve *e* allowed the foul air to escape, and prevented the entrance of the water. The valve-spindle was immediately closed on the least stoppage of the supply of air by means of a spiral spring, as well as by the pressure of the water. The valve being slightly loaded prevented the pressure of the water acting on the body of the diver, in consequence of the internal pressure being greater than the external.

DIVING BELL. Fr., *Cloche de plongeur;* Ger., *Taucherglocke;* Ital., *Campana da marangoni;* Span., *Campana de buzo.*

W. Forsyth, in the T. I. C. E., Ireland, says that the best contrivance of this kind is the bell generally attributed to Smeaton, and improved by Rennie. Various modifications have been introduced by others, and different sizes have been tried, some larger, and some smaller than Rennie's; but, for the general purposes of hydraulic architecture, this bell has maintained its superiority, and is in general use while the others are abandoned. It is, however, not without its defects: and these defects are severely felt by those engaged in particular branches of these operations. The most prominent are the following;—Its great weight, and the being compelled to use one uniform weight for all depths and purposes coming within the range of its operations.

In constructing the submarine foundations of piers, and so on, at a great depth, this weight is absolutely necessary; it has even been found that the mechanical contrivances used for managing the bell have but little command over it, from its buoyancy at such depths. The great weight being in the substance of the bell itself, gives it greater compactness than if the weights were foreign to its own substance, and merely attached to give it preponderance.

It has also been found that building under water to seaward, even at small depths, weight, strength, and compactness are highly necessary, as the agitation of the sea drives the bell about with dangerous force, notwithstanding its weight; and the shocks it has to sustain, when driven against stones, might displace attached weights, and destroy a weaker machine.

These are facts which have been proved by experience, and they are of importance to those concerned in hydraulic operations of this kind. But in sheltered harbours, lakes, and rivers, where the depth is often small, and the water still, the bell is not exposed to a force that would displace it, derange any of its attachments, or endanger its structure. And there are many operations, such as blasting rocks, making excavations, lifting stones, and so on, where it would be of great advantage to possess a light machine, which could be easily transported from place to place, and even taken asunder to facilitate its transport, and which would require little time or skill to rig it up; and besides dispensing with much of the gigantic machinery by which diving bells are now worked, to be able to regulate the preponderating weight according to the depth at which the operations are being carried on.

Bells constructed of timber have been used, even for building purposes, with considerable success; and for lifting guns, anchors, merchandise, and so on, from wrecks or places where they have been lost overboard, a bell constructed of timber, and jointed with canvas, so as to fold up, has been used. There is nothing to prevent such machines being used, as the pressure which they

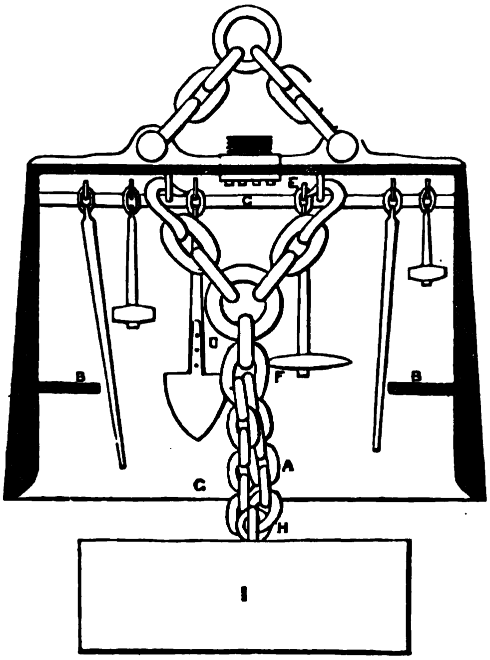
have to resist is seldom more than 3 or 4 lbs. the square inch; but they are so fragile that their use could only be temporary at best.

The extensive application of sheet iron, especially to hydraulic purposes, at once points it out as the most durable and economical material that can be employed, and as possessing all the properties necessary for constructing a light portable bell, capable of being loaded to an extent to suit any depth of water.

The size of the diving bell for general purposes ought to be the same as Rennie's bell; the size of this bell is 6 ft. 4 in. long, 3 ft. 10 in. wide, and 5 ft. 4 in. high, internal dimensions. To add to its dimensions in any way would be to add to the weight necessary to sink it; and although this weight would be neutralized by the included atmospheric air when immersed, yet the whole weight would have to be borne when the bell was lifted out of the water, or else the weights removed when it came over water; either of these would be attended with cost and inconvenience. Jumpers of any length can be used in Rennie's bell. It is only necessary to have them in suites, increasing in length in a certain ratio, so that they can follow each other. If the hole to be bored be a vertical one, when it is put down so far as to make it necessary to introduce a longer jumper than can be turned within the bell when set on the bottom, then all that has to be done is to have the bell hove up to a sufficient height to allow the jumper to be introduced, and lowered down again. If the hole be horizontal or inclined—what is technically called a lifting shot—then, instead of the bell being raised, it has to be moved to one side, the long jumper introduced, and the bell then returned to the former position. There are many of these little contrivances known to the workmen practised in this kind of work, which enable them to surmount many seeming difficulties.

For blasting rock in depths under 10 ft., much time and expense would be saved by the following plan. Let the workmen in the diving bell select a proper place for the proposed shot, and enter a hole, say 12 in., then jumpers of sufficient length could be introduced to enable the hole to be completed to any required depth from a flat—similar to the boring flats used on the Shannon—or from a raft or scaffold. When the hole is completed to the required depth, the charge can be put in and stemmed by the workman in the diving bell; and as it is seldom that less than 3 yds. of fuze are used for the safety of the workmen, the end can be brought to the top of the water and fired.

2453.

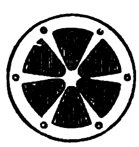


If this plan be followed, about one-half of the usual cost of boring under water would be saved, as the divers would have little more than a fourth of the work to do. The numerous attendants on the bell, and the necessary slowness, in comparison to working on a lighter or raft, will warrant these statements. If the rock be of such a kind that horizontal or inclined holes are necessary, this plan cannot be followed, but a hole inclined 50 or 60 degrees may be bored in this way.

To make the internal economy of the diving bell intelligible, a section of Rennie's bell is given, Fig. 2453.

A, is a foot-board which is movable, and seldom used, except when descending and ascending. B B, two seat-boards; these are also movable, being inserted between raised flaunch brackets, cast on the side of the bell. C, a timber rail, wedged between the ends of the bell, and placed in the angle which the top and sides make; there is one on each side. Malleable iron hooks are driven into these rails, from which the tools are suspended, namely;—two setting bars, a shovel, one or two boring hammers, a 3-ft. rod, several chains, and the signal hammer. These are the tools always necessary, excepting the shovel. For occasional work, such as boring, there are jumpers and tampers of various sizes; but these, and heavy chains and hammers, are left lying at the bottom when not being used or undergoing repair. D, are the inside coupled chains, these are also made so as to be detached with ease. E, the air-valve attached to a brass grating of the form shown, Fig. 2454, which is secured to the top of the bell by screw taps. The valve is simply a disc of strong leather held in its place by the screw taps which fix the brass grating to the top of the bell. F, the coupling chain, by which stones and other weights are lifted. G, the line at which the water usually stands on the inside of the bell, when the air-hose is in good order. H, the *lewis*. I, stone suspended by the lewis and chains. The

2454.

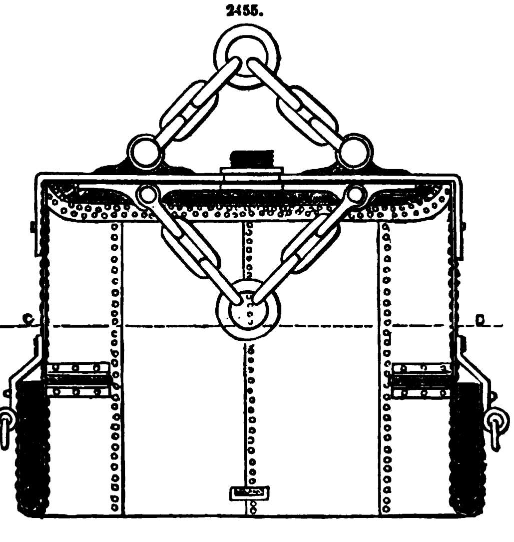


use of the greater part of these is obvious. The use of the internal coupled chains will also be understood by the manner in which the stone is represented, as suspended, in the sketch.

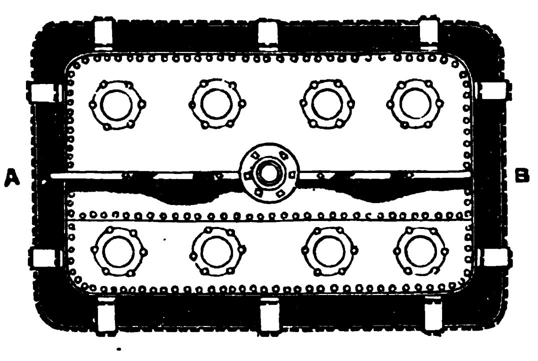
If we suppose, for illustration, a stone to be lowered down; the bell is then brought over it, and made to rest slightly on the stone to steady it. The chains by which the stone was lowered down are then detached; the lewis having been inserted into the stone before it was lowered, is attached to the inside coupled chains in the following manner;—the chain F, which forms an indispensable item in the furniture of the bell, has a hook at each end, one much stronger than the other: the strong hook lays hold of the ring which couples the two inside chains D. The other end of the coupling chain is run through the ring of the lewis, and either hooked into the ring beside the large hook, or, what is more common, four large links are made on the end of the coupling chain F next the large hook, and into one of these the small hook is hooked, suiting the length to the proper distance between the bottom of the bell and the stone when suspended. When this is done, the bell is then hove up, and as the stone is attached to the bell by the chains F and D, the stone is also hove up, and, when high enough, carried away in obedience to the signals.

When the bell is prepared for boring, every implement that can be dispensed with is removed to make room. One or both of the seat-boards are taken out to make seats on the rock, or scaffolds to stand on. If the hole be a horizontal or inclined one, it is necessary that the bell be so far raised as to allow the jumper to be put out under the end of the bell; then the foot-board and seat-boards are made into a scaffold by suspending them from the hooks in the timber rail, by lanyards or gaskets. When the hole is bored, the bag or cartridge is introduced, and tamped in the ordinary way, only clay will not answer, it becomes too soft with the water—soft burnt brick must be used. About 3 yds. of fuze being left attached to the bag, the seat-boards and foot-boards are replaced, the end of the fuze is kept in the bell, which is now removed as far as the length of the fuze will permit. The fire is then applied, and the bell removed farther—about 5 or 6 yds. in all—from the shot. This is quite far enough for safety, as no fragments will be able to force their way through the water to do any injury.

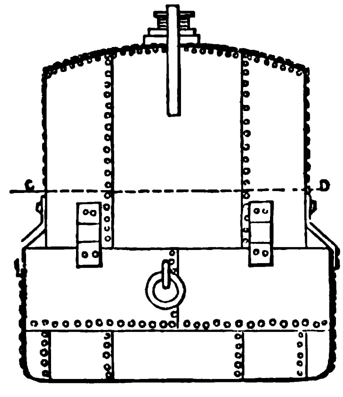
2455.



Forsyth designed a sheet-iron diving bell, represented Figs. 2455 to 2457. It is made the same as Rennie's bell in size, although a smaller bell might be occasionally used with great advantage. The plates are $\frac{1}{8}$ or $\frac{3}{16}$ of an inch thick, 6 ft. 6 in. long by about 2 ft. 3 in. broad. These plates should be placed in the manner shown on the drawings —that is, the seams or joints of the sides and ends to be vertical, and the lower ends of the plates turned up so as to form a receptacle for the ballast weight. As the length turned up will not give sufficient depth to this receptacle—or what may be called pocket—Forsyth proposed that a plate be joined horizontally, or its length parallel to the bottom of the bell, and continued quite round, forming a continuous band to give strength to the pockets at the corners, where the plates are necessarily



2457.



cut to allow them to be turned up at the bottom. Forsyth designed the pockets to be 20 in. or more deep. If 5 ft. 4 in., the height of the bell, be taken from 6¼ ft., and 7 in. for the semi-cylindrical bottom of the pocket from the difference, there will remain only 7 in. of the side and end

plates to be turned upwards for the outside of the pockets. It will therefore require a plate 16 in. or more broad, allowing for the seam, to make the pocket of the proposed depth, not taking the semi-cylindrical bottom into account. Instead of piecing each turned-up plate with 16 in. in length, Forsyth took four plates, about 6 ft. long each, and 16 in. broad, which, when joined together by riveted seams, will make a continuous band entirely round; and this band is joined to the turned-up ends of the vertical plates by a riveted seam.

To this continuous horizontal plate are attached knee-plate stays, 4 in. broad and ½ in. thick. These stays are riveted to the sides and ends of the bell, three on each side and two on each end. The top of the bell is attached to the sides and ends by angle-iron, such as is used in the construction of steam-boilers. The corners of the bell form a portion of a cylinder—6 in. radius—to facilitate the bending of the plates, and avoid straining them; this will also assist the bending of the angle-iron round the corners and ends of the bell. The cylindrical corners of the bell make it necessary that about 12 in. in breadth be cut out of the middle of the plate, from the line which terminates the vertical part of the plate forming the body of the bell to the end of the plate. When the portions of the plate remaining after this piece is cut out, are bent upwards, the ope must be covered with a piece of plate forged to the proper figure. The cutting and forging of the corners of the pockets will leave them weaker, and therefore it is desirable to have the continuous band to strengthen them.

The top of the bell is formed of two pieces of plate of unequal breadth, to avoid having the riveted seam in any of the perforations. A bar of iron is placed on the top and extending its whole length, except where the air-hose is attached to the top of the bell, and turning down on each end. The general dimensions of this bar are 2 in. square, and thinned towards the inverted ends; and having two pedestal-formed parts, as shown, to receive the shackle-bolts of the coupled chains by which the bell is suspended. These shackles, bolts, chains, and ring, to be the same as those of the bell now in ordinary use. A similar bar is on the inside of the bell-top, but shorter, not having its ends inverted. These bars are to be attached to each other and to the bell-top by four rivets of 1¼ in. round iron riveted hot; and the two inverted ends of the top bar to be secured to the ends of the bell by one rivet each. To the inside bars the coupled chains for lifting weights are attached by shackles and bolts. The screw-joint for receiving the end of the air-hose, and the valve on the inside of the bell, to be of the same materials and construction as the bell already referred to. The perforations for the lights to be 5 in. in diameter, the lenses 7 in. in diameter, and 2 in. thick in the middle. The lenses to be secured with glands, hemp, and luting of red or white lead, and fastened to the top of the bell with screw-taps. The number of lights to be eight, the usual number is ten. The position of the two deficient ones is occupied by the bar above described. This bar was considered necessary to prevent straining the angle-iron, by which the top of the bell is attached to its sides and ends; and perhaps it may be advisable to have two other bars placed at right angles to this one, proceeding from the pedestal parts, and turning down the sides of the bell and riveted in the manner before described. These bars are not shown on the figures.

The air-pump and air hose or pipe to be the same as those in general use.

The ballast to be of cast iron, moulded of such shapes as will fit the pockets, and provided with handles sunk below the surface.

On an emergency, or where it might not be convenient or advisable to transport the ballast, malleable iron bars of suitable lengths, and any scantling, may be used, so that they stow into the pockets and fill them.

If the weight of the bell, about 32 cwt., be found too great for transport, it may be made in two divisions—see line *c*, *d*, on Figs. 2455, 2457—and joined together by a series of screw-bolts instead of rivets, and having a band of hemp or canvas luted with red-lead interposed between the parts to make the joint air-tight. It is, however, evident that this ought to be avoided if possible.

DOCK. Fr., *Bassin de construction*; Ger., *Werftdocke*; Ital., *Bacino*; Span., *Dique*.

A *dock* is an artificial enclosure in connection with a harbour or river, used for the reception of vessels, and provided with gates for keeping in or shutting out the tide.

A *dry dock* is a dock from which the water may be shut or pumped, so as to leave a ship dry for inspection or repairs; called also a *graving dock*.

Floating dock, a structure, either water-tight or provided with water-tight tanks, for receiving vessels and raising them out of water by its buoyancy, when the water is pumped out of it, or out of the tanks, or the tanks are lowered by machinery; called also *sectional dock*.

Naval dock, a dock connected with which are naval stores, materials, and all conveniences for the construction and repairs of ships.

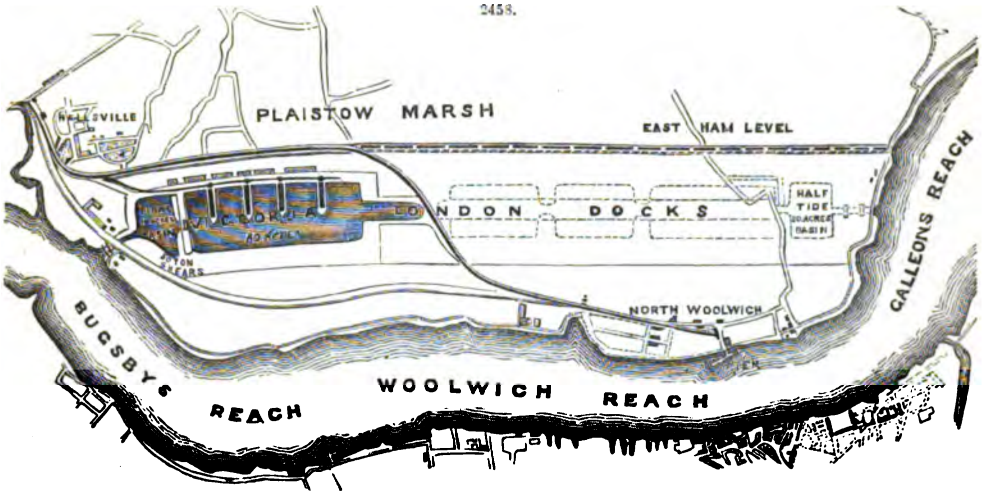
Screw dock, a dock in which a frame for the reception of vessels is raised or lowered by screws and other machinery.

Wet dock, a dock where the water is shut in, and kept at a given level, to facilitate the loading and unloading of ships; a basin.

The Victoria Docks are situated near Blackwall, London, and occupy an area, inclusive of the entrance lock and eastern channel, of nearly 100 acres of water, or of 200 acres of land and water. Fig. 2458 gives the position and shows the plan of these docks. The water area comprises the entrance lock from the Thames, with two pairs of gates, leading by a channel into the tidal basin of 16 acres, which is separated from the main dock of 74 acres by a dumb jetty, but communicating with it by a single pair of gates, and terminating, at present, with a cut or channel at the eastern extremity. In general terms the basin and dock together (exclusive of the eastern cut) are 4050 ft. in length and 1050 ft. in width at the level of high-water mark. In addition to the dumb or separating jetty, there are four other jetties projecting into the dock from the north side, each 581 ft. long and 140 ft. wide, which are placed 430 ft. apart, except the most easterly one, which has an interspace of 550 ft. The jetties, with the sides of the dock and of the basin, provide a length available for quay room of nearly 3 miles. The surface of the marsh, which is nearly

level, is about 8 ft. 6 in. below Trinity high-water mark, and, previous to the construction of the docks, it was drained by open ditches carried by means of culverts with trapped outlets through the ancient river bank into the Thames. This bank, which protects the lands from the tidal water of the river, is maintained at a height of 5 ft. above Trinity high water, and this is the level adopted for the top of the copings of the entrance and entrance-lock walls.

2458.



It may be well, while speaking of the Trinity high-water mark (a convenient datum to which to refer depths), to state that the bottom of each of the two docks is 24 ft. below this standard, the depth of the channel leading to the lock from the basin is 25 ft. 8 in., on the sill of the upper gates 25 ft. 6 in., and in the lock itself and on the lower-gate sill 28 ft., a depth which is maintained through the entrance into the river. As the mean fall of tide is 18 ft., there is, therefore, on the lower-gate sill a depth of 10 ft., and on the upper-gate sill a depth of 7 ft. 6 in., at Trinity low-water mark.

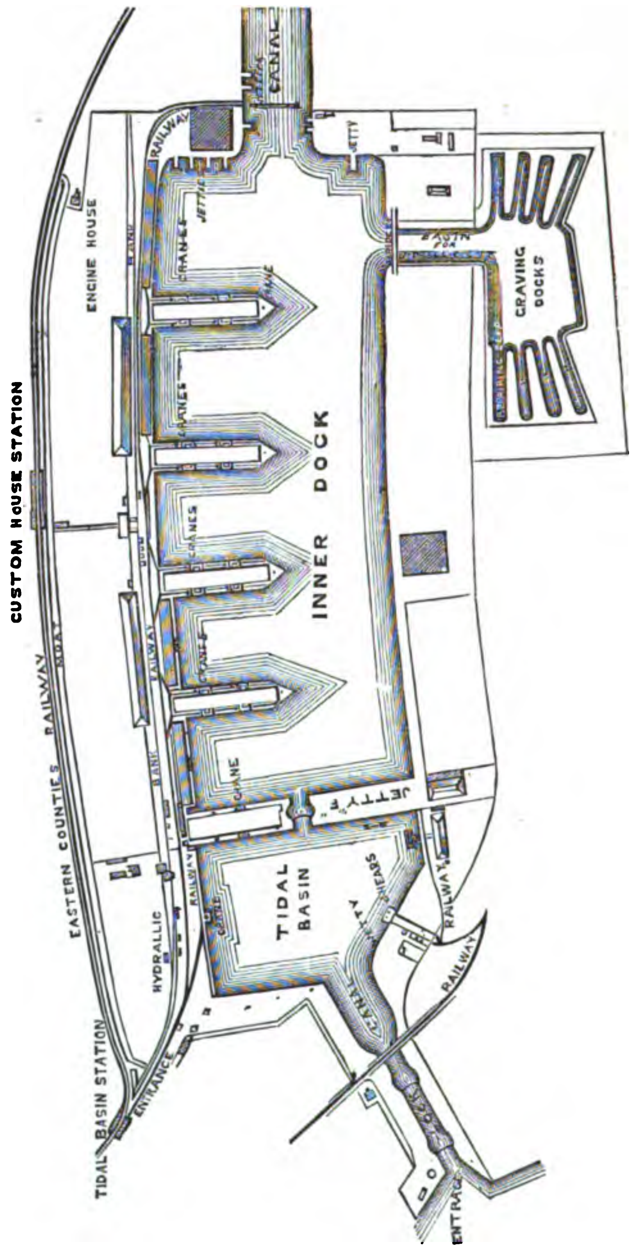
The subsoil, beneath a layer of about 12 in. of topsoil, may be briefly described to consist of various thicknesses of yellow and blue clays, averaging together 5 or 6 ft. in depth, then a stratum of peat, of no economical value, varying from 5 ft. to 12 ft. in thickness, and beneath this a bed of gravel, overlying the London clay. At the entrance, the upper clay-beds were from 8 to 9 ft. thick, the peat about the same, and the gravel 10 ft. thick near the lower-gate platform; but in the middle of the lock-chamber the gravel diminished in thickness to 7 ft., increasing again to 8 ft. at the upper-gate platform. Hence the solid clay substratum was found, throughout the length of the lock, at a nearly uniform depth of 37 ft. below Trinity high-water mark, and on this foundation, at a depth of 37 ft. 6 in., the brickwork of the upper and lower gate platforms was laid.

Entrance and Entrance Lock.—Proceeding somewhat more in detail, it will be seen from the plan, Figs. 2458, 2459, that the channel, which on leaving the tidal basin is 156 ft. wide, contracts as it approaches the lock at the swing bridge, after passing which the side walls, throughout the lock and entrance, are constructed of cast-iron piling and plates, backed with concrete, but interrupted in two places, for the brickwork of the gates. The piling has a batter of 2 in. in a foot, and where it commences the width between the copings is 91 ft., which continues for a length of rather more than 100 ft. The brickwork of the upper-gate platform then begins, and occupies a length of 83 ft. 3 in., the side walls being here vertical and 80 ft. apart; then the lock-chamber, Fig. 2460, with concrete walls and cast-iron piles, as before, for a length of 256 ft. 10 in.; then the lower-gate platform 73 ft. 3 in. in length, giving a lock-chamber 80 ft. wide at the bottom, 326 ft. 6 in. long from gate to gate, Fig. 2465, and with a depth of water of 10 ft. on the sill at low water. Beyond this point the piled and concrete side walls recommence, running parallel for a length of 85 ft., and then widening out, for a farther distance of nearly 200 ft., in a trapezoidal form, the base, or greatest opening, being 385 ft., and the unequally-inclined sides being respectively 297 ft. and 160 ft. in length, the longer one being that next to the Bow Creek.

The cast-iron piling and concrete wall are very similar to those already successfully employed in the construction of the Brunswick Wharf, Blackwall, and at Fleetwood Harbour. The cast-iron piling is formed in bays, which are 7 ft. 1 in. from centre to centre of the main piles, the intervening space being filled, for a distance of 15 ft. from the top, by three cast-iron plates, retained laterally by the edges of the main piles which stand in front of them, the lower part beneath the plates being made up with four cast-iron sheet-piles, on the top of which the bottom plate rests, its lower edge being furnished with a rebate or fillet which hides the joints and maintains the piles in their position. The main piles are each in two lengths; the lower one, which is 25 ft. long and 18 in. wide on the face, is provided with two vertical flanges, or feathers behind, 8 in. deep and 12 in. apart, the metal being about 2 in. thick; and the upper one, which is 12 ft. 8 in. long and 18 in. wide, has a section similar in form, but somewhat lighter in substance: it is placed on the former, and is secured by bolts passing through it and fish-pieces cast on the upper length for the purpose, proper chipping pieces being provided to ensure accurate fitting. The sheet-piles, which

are each in one length of 20 ft., are of somewhat similar form; but it will be unnecessary to go into a more minute description of them, as the particulars are fully given in Figs. 2466 to 2468. The three top plates are each 5 ft. 11 in. wide and 5 ft. deep. They are furnished with the necessary back feathers to give them strength, the upper one being so arranged as to carry the front edge of the stone coping of the wharf, which is 18 in. in thickness. In the rear of each main pile, and at a distance of 18 ft. from it, a timber land-tie 20 ft. long is driven to the same depth as the cast-iron piling. Through the head of this two wrought-iron tie-rods, 2 in. in diameter, are passed, and secured by means of washer-plates and nuts; the lower one is connected with the upper end of the lower length of the main pile by means of an eye-bolt, and the upper one is attached to the upper main pile, at a distance of 8 ft. above the former, and in a similar manner.

2459.



In the part between the lock and tidal basin, the channel was excavated to a depth of 27 ft. 8 in. below Trinity high-water mark, to receive a thickness of 2 ft. of clay puddle. The main piles were driven 5 ft. into the gravel, the sheet-piles entering 2 ft. 6 in. into it. The concrete wall was carried to the bottom of the clay puddle; and the whole space at the back, between the concrete wall and the land-ties, was filled in with gravel, well rammed. In the lock-chamber, the gravel in the bottom was taken out, down to the clay, except a portion on each side, into which the piles were driven, and on which concrete was laid in front, forming a toe to the wall, and sloping down towards the centre, Fig. 2463, and the whole intervening space was filled with clay puddle to the proper level.

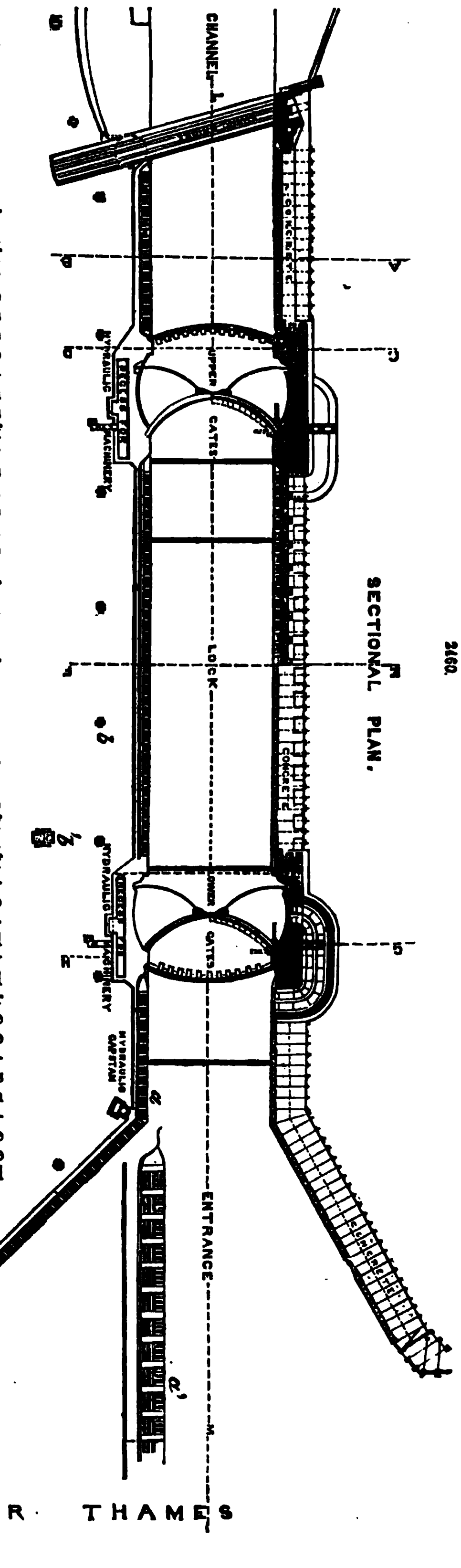
Beyond the lower-gate platform the concrete walls were carried, for the full thickness, to the back of the land-tie piles, and on a level with the top of them, or about 15 ft. below Trinity high-water mark. The walls were then reduced in thickness to about 10 ft., and were carried up vertically at the back, giving, in consequence of the batter of the front piles, a thickness of 6 ft. at the top, as in the other cases. The wharf wall is finished off at the top in the front by a stone coping 18 in. thick and 3 ft. on the bed.

The concrete was composed of clean gravel, containing two-thirds coarse and one-third sharp grit, and Halling lime in the proportion of six to one. The lime was not ground, but used hot, and the concrete was found to set very hard.

Upper and Lower Gate Platforms.—It has been already stated that the London clay was found at about 37 ft. below Trinity high-water mark. In consequence of a good, and at the same time an impervious, foundation occurring at a convenient depth, an invert was dispensed with, and ordinary brickwork in level courses was employed, Figs. 2462, 2464. Areas 120 ft. wide and 83 ft. 3 in. long for the upper platform, and 120 ft. wide and 73 ft. 3 in. long for the lower platform, were laid bare down to the London clay, and round each of them a single row of elm sheet-piles, 16 ft. in length and 8 in. thick, was driven close, to a depth of 6 or 7 ft., into the solid clay, the heads being levelled and secured by walings; and within the spaces so enclosed the brickwork of the platforms was laid. The thickness of this brickwork in the case of the lower gates was 8 ft. 6 in., reckoning to the under-side of the shutting sill, over that portion of the area traversed by the gates and included between them when open; while the rest was carried up a foot higher, or 9 ft. 6 in. to the top of the shutting sill. The sill of the upper gates being 2 ft. 6 in. higher than the lower sill, the thickness of the brickwork is here reduced to 6 ft. 6 in. and 7 ft. 6 in. in situations corresponding to those previously described; but as the clay is found here at the same level as at the lower platform, the additional depth of 4 ft. 6 in. is made up with concrete. It will be seen that the sufficiency of this mode of construction is mainly dependent upon the means and care taken to prevent the water from getting to the under-side of the brickwork, and blowing it up by its lifting power. The weight of the brickwork is wholly inadequate to resist the lifting power of the water. For example, in the case of the lower-gate platform, with the water standing outside at the level of ordinary Trinity high water, the pressure of the water on the under surface of the brickwork, if it had access there, would be more than 2300 lbs. a square foot, while the weight of the brickwork inside, with 10 ft. of water upon it, would only amount to 1640 lbs. a square foot. See DAM. Hence the importance of taking out all the gravel, in order to bring the brickwork and concrete into direct contact with the impervious clay, and the advantage, if not necessity, of the precaution of covering the horizontal joints with the close sheet-piling. In this way the access of the water to the under horizontal surfaces is so interfered with, that its lifting power is effectually neutralized without the help of the side walls, as when an invert is employed, at the same time the horizontal disposition of the brickwork, perfectly free from all complexity, affords the greatest facility for bedding holding-down plates for the shutting sills, pivot-crosses, roller-paths, and so on. Upon these platforms the side walls are carried up in brickwork, including the copings, to heights above the sills of 33 ft. and

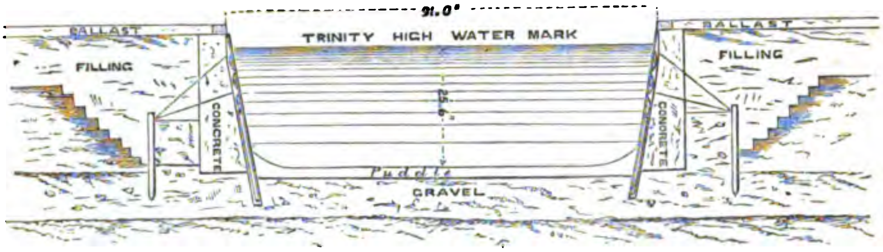
2460.

SECTIONAL PLAN.



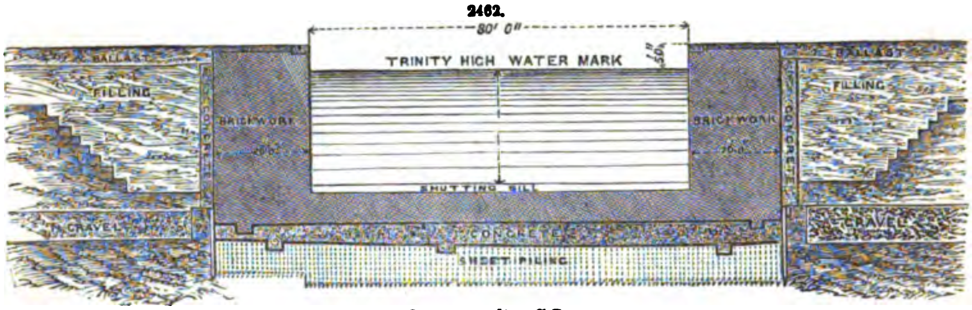
30 ft. 6 in. respectively, and at a minimum distance apart of 80 ft. They are 20 ft. thick where they connect with the concrete walls and iron piling, and continue so till the curved recesses for the gates commence, by which the thickness is reduced to 11 ft. in the central part of the hollow.

2461.



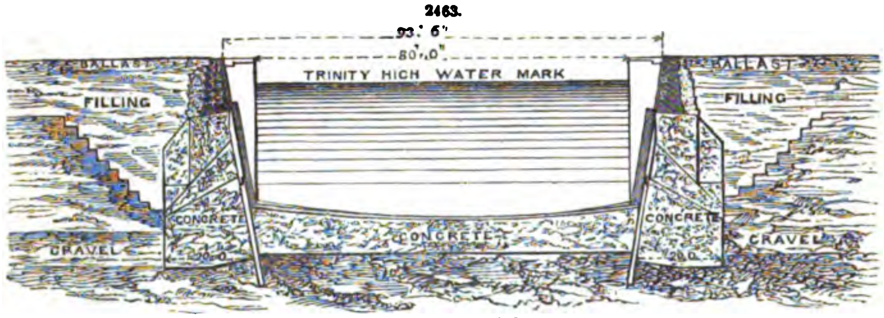
Section on line A B.

2462.



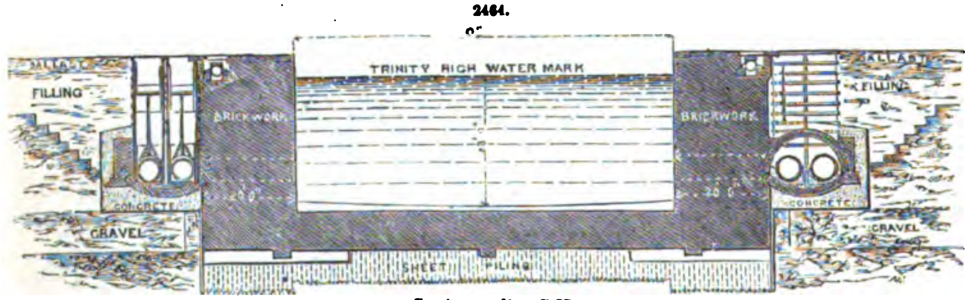
Section on line C D.

2463.



Section on line E F.

2464.



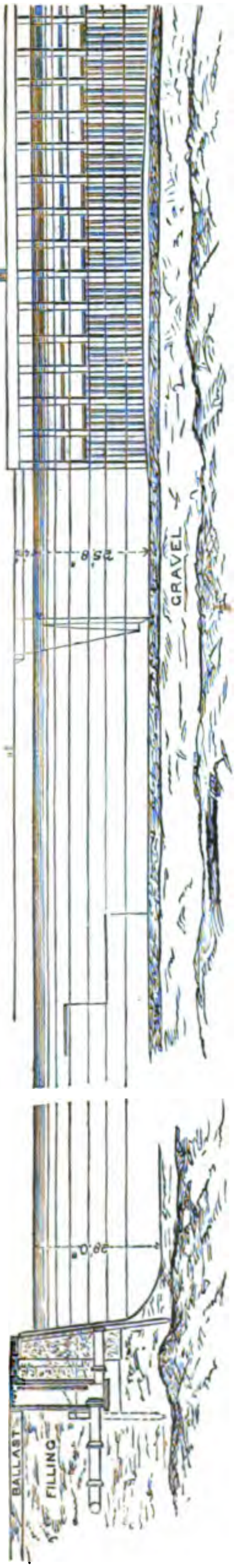
Section on line G H.

The hollow *quoin* is a portion of a circle, having a radius of 12 in., and the length of the arc of contact is also 12 in. Vertical chases are left in each side wall for receiving the roller-frames when the gates are opened back, the break in the coping being covered with a cast-iron plate. Chambers are also provided for the chain roller boxes and chain ways, which are of the ordinary description, lead up to the vaults containing the hydraulic machinery, Fig. 2460, for moving the

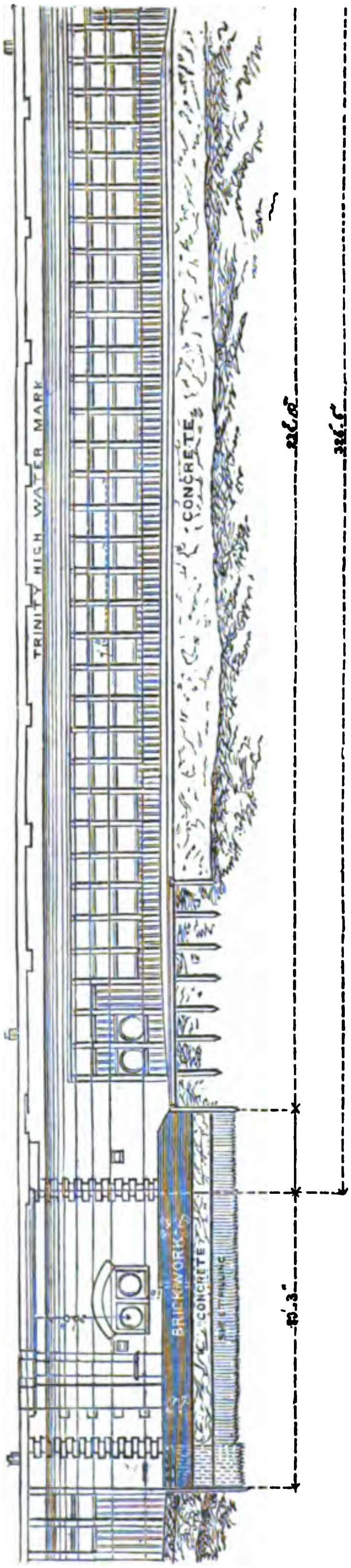
2466.

Section on line L M.

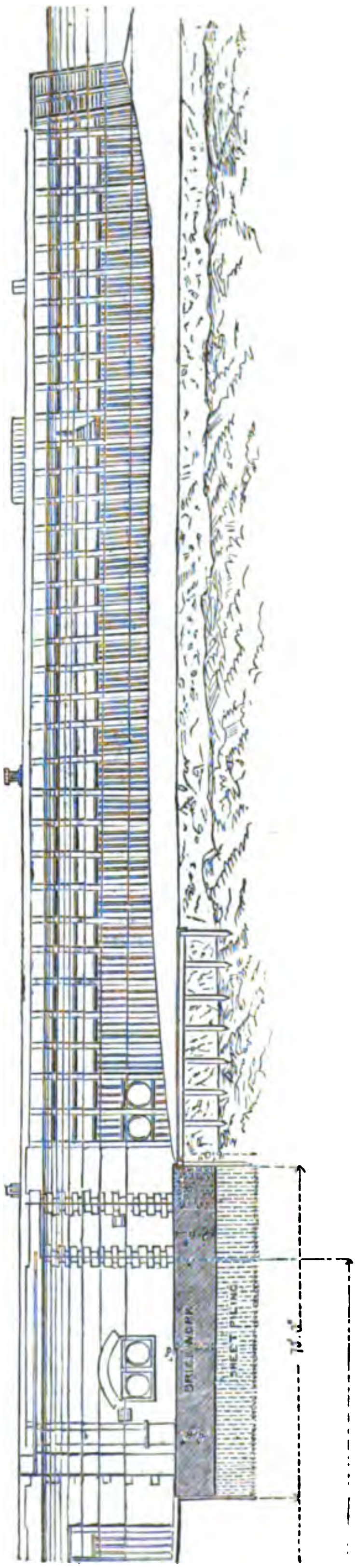
Section on line I K.



Section on line L M—*continued.*

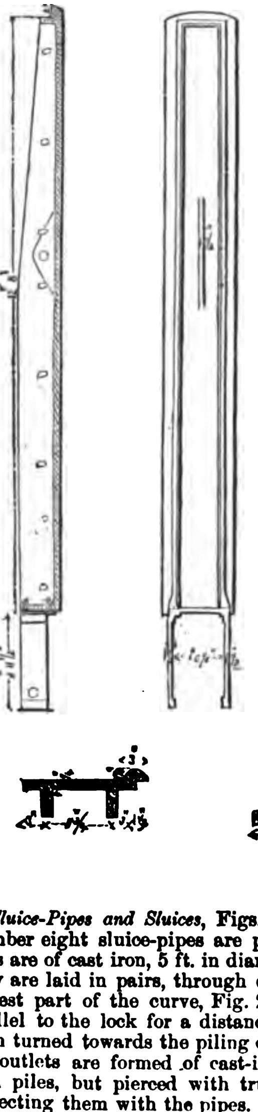


Section on line L M—*continued.*

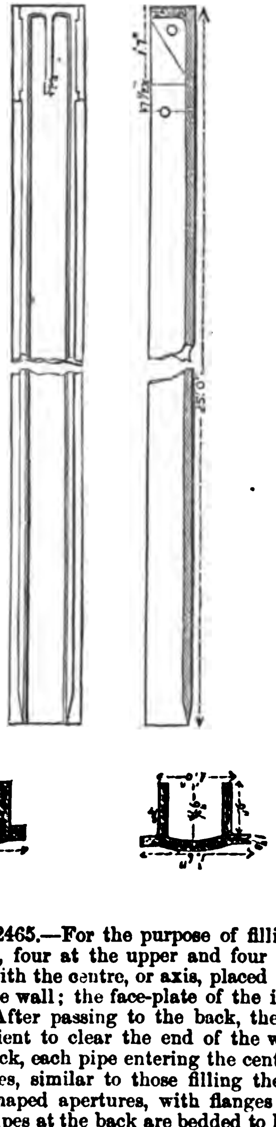


gates, which is situated just beneath the upper level of the wall, and to the rear of it. The side walls at the ends are raked round in a double-curved form, to meet the batter of the piled and concrete wall of the lock-chamber, so as to avoid a sharp vertical arris. Where the vertical part terminates, at the east end of the wall of the upper gates, and the west end of that of the lower gates, a hollow *quoin*, somewhat similar in form to that for the gates, is placed to receive the caisson, a step, or sill, being provided in the bottom for the same purpose. The hollow quoins, the external arris of the gate recess, the caisson quoins and sill, and the copings and bed stones for the anchors (see ANCHOR), were made of a compact sandstone, and these constituted all the stone employed, with the exception of that required for fixing the hydraulic machinery. The brickwork was composed of bricks made of clay from the excavation, faced with Maidstone bricks, laid in mortar, composed of clean sharp sand, found on the site of the docks, and Halling lime, *gauged* in the proportion of two to one.

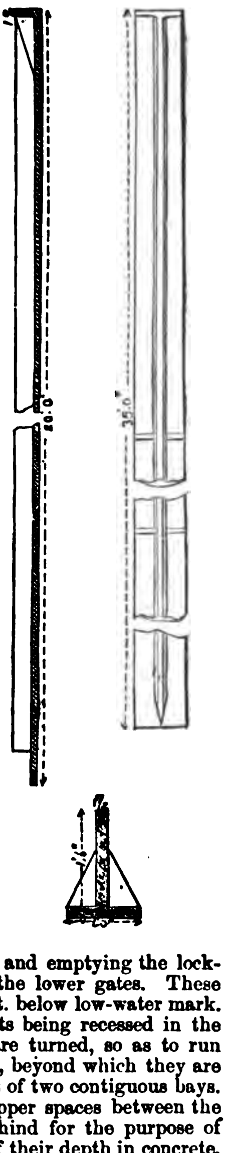
2466. Piles.



2467. Piles.



2468. Piles.



Sluice-Pipes and Sluices, Figs. 2464, 2465.—For the purpose of filling and emptying the lock-chamber eight sluice-pipes are provided, four at the upper and four at the lower gates. These pipes are of cast iron, 5 ft. in diameter, with the centre, or axis, placed 9 ft. below low-water mark. They are laid in pairs, through each side wall; the face-plate of the inlets being recessed in the deepest part of the curve, Fig. 2460. After passing to the back, they are turned, so as to run parallel to the lock for a distance sufficient to clear the end of the wall, beyond which they are again turned towards the piling of the lock, each pipe entering the centres of two contiguous bays. The outlets are formed of cast-iron plates, similar to those filling the upper spaces between the main piles, but pierced with trumpet-shaped apertures, with flanges behind for the purpose of connecting them with the pipes. The pipes at the back are bedded to half their depth in concrete, laid in a brick culvert 16 ft. in diameter, the open space above the pipes affording facilities for examination, and for the execution of any repairs that may be necessary, without disturbing the more solid work.

The sluices are similar to those used in water-works. The paddles are of cast iron, faced with

brass. A cast-iron trunk, with an internal capacity of 6 ft. by 2 ft., is brought up from each to the coping level, in the upper part of which is contained the hydraulic apparatus for lifting and closing the sluice-valve. These trunks permit the paddle to be easily withdrawn for repair. Provision is also made by which all the sluice apparatus from the bottom can be taken out, without disconnecting the pipes. In this, as in every other case where it was practicable, the principle was acted upon—to afford, in the arrangement of the design, and during the construction, every possible facility for the subsequent examination and repair of those parts which are most liable to get out of order.

The portion of the lock bottom beneath the outlets, and therefore exposed to the wash and disturbing action of the water, is floored for a length of 50 ft., from the termination of the brick platform, and for the full width, with creosoted planking, secured by means of walings to piles, driven 7 ft. apart over the area. The spaces between the heads of the piles, the walings, and the planking are filled in with concrete to a depth of 2 ft.

The Wrought-iron Gates.—Of these there are three pairs; the upper and lower gates of the entrance lock, Figs. 2469 to 2476, and the inner gates, separating the tidal basin from the main dock. The upper and inner gates are of the same dimensions; and the same general arrangement being employed in the three sets, a description of the lower gates will be sufficient for the present purpose, leaving a few minor differences to be pointed out afterwards.

Until within a comparatively recent period, timber was exclusively employed in the construction of lock gates; and while they remained of moderate dimensions, this material was well adapted for the purpose. But with the increased size of ships now employed in commerce, demanding larger lock entrances and gates, the difficulty of finding timber of sufficient length and scantling, and then of giving it the necessary curvature, has become so serious as to render the use of iron almost a necessity. In the earlier examples cast iron was employed for the internal framing. This was generally covered with planking, but in some instances wrought-iron plates were used instead of the planking for the skins of the gates, advantage being taken of the opportunity afforded by this arrangement to diminish the weight on the points of support, by the flotation obtained by excluding the water from the interior of the gate. The cast-iron framing is now advantageously superseded by the use of wrought iron, so that the whole gate, with the exception of the heel and mitre posts, and shutting sill, which are generally either of wood or of cast iron, is constructed of this convenient material, which, combining strength with lightness, avoids at the same time the lesser evils of unequal expansion, screwed connections, and other inconveniences, as well as the risk of fracture from sudden blows, to which cast iron is liable. For the gates of the Victoria Docks timber would have been very unsuitable, not only on account of their large dimensions—the lower gates having a span of 80 ft., and a height of 31 ft.—but because of the considerable amount of curvature given to them, the versed sine being 20 ft., or one-fourth of the span.

The form of the outer curve of the pair of gates is the arc of a circle having a radius of 50 ft., the distance between the skins at the heel and mitre posts being 2 ft., and at a point midway between them, 3 ft. The inner boundary is formed of two arcs of circles struck from centres 9 ft. 5½ in. apart, with a radius of 59 ft. 9½ in. The space between these curves represents the form of the fourteen horizontal diaphragms in each leaf, varying in distance apart from 1 ft. 11 in. at the bottom to 3 ft. at the top, and placed parallel to the floor of the lock, with the exception of the bottom one, which is sloped 9 in. upward at the heel-post, to give more room beneath for the cast-iron step-piece and pivot. On the under-side of this bottom plate, which is ¾ in. thick, is secured, by means of T-iron bracket-pieces, the timber which meets the cast-iron shutting sill. This is made of green-heart, 9 in. deep and 4½ in. thick.

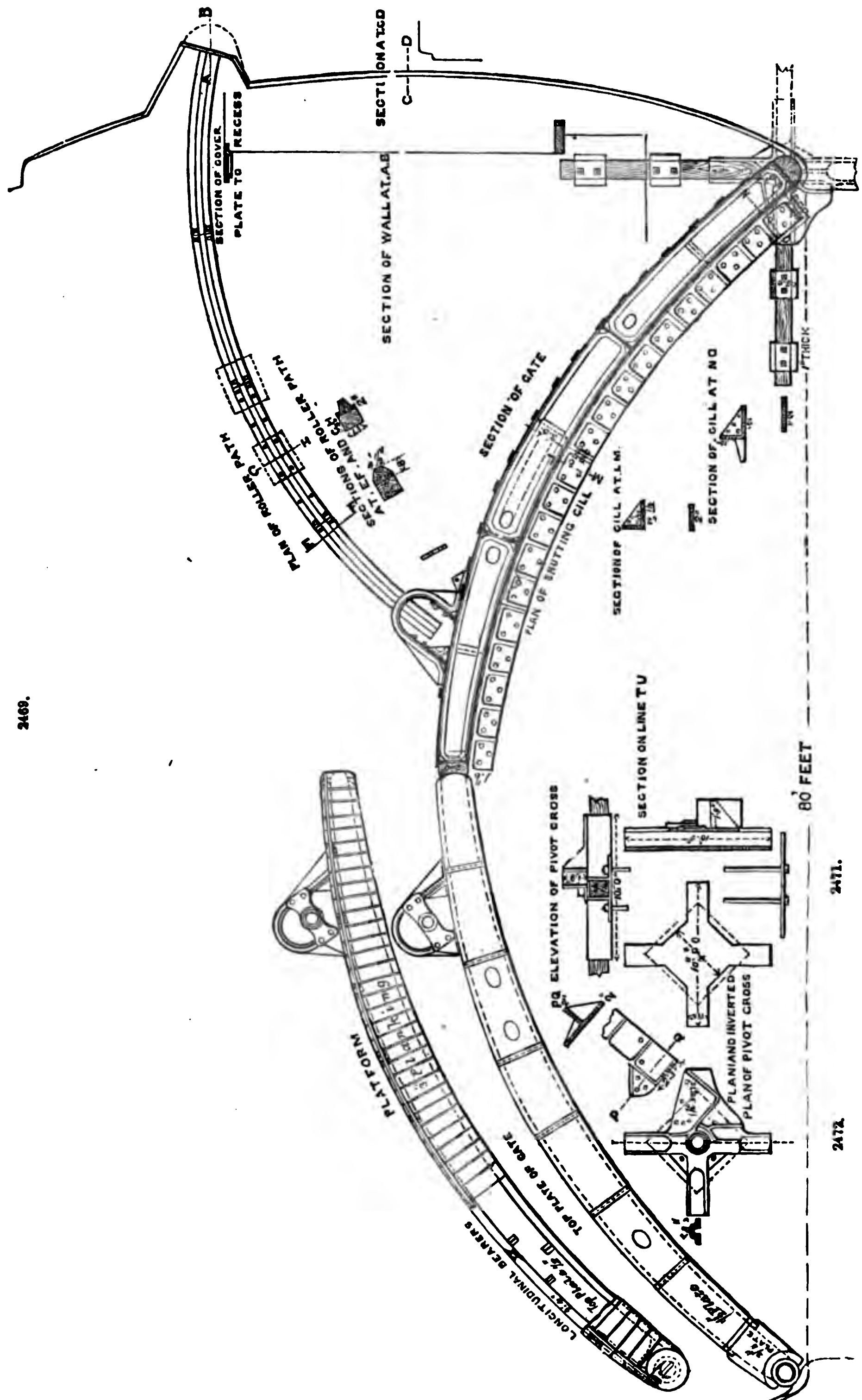
The other horizontal diaphragms are ½ in. thick, and are connected with the skins by T-iron, 4½ in. by 2½ in. in section, and by angle-iron 2½ in. by 2½ in. in section. There are also two vertical diaphragms which divide each leaf into three nearly equal parts, passing continuously from the top to the bottom, and therefore intersecting each horizontal diaphragm, the T-irons and angle-irons of which are brought round and riveted to the vertical diaphragms. This arrangement subdivides the horizontal cellular spaces, and also prevents the gate from twisting. Man-holes are provided in each compartment through each diaphragm, to give access to every part of the gate, and they are closed by covers at the proper level for giving the requisite amount of flotation. Of the framework thus constructed the outside plating is riveted. This varies in thickness according to the amount of strain it has to bear, from ¾ in. at the bottom to ½ in. at the top. The plates are disposed with their lengths placed vertically, all the joints being provided with strips on the outside and on the inside, to ensure their being water-tight. Short horizontal strips are also required, where, from the passage of the vertical diaphragms, it is impossible to calk the horizontal T-irons quite close into the corners.

In the caisson, which was constructed subsequently, the widths of the plates forming the skins were placed vertically, and with advantage.

The heel and mitre-posts, which are of green-heart timber, are bolted to the strong vertical plates forming the terminations of the ironwork of the gates. They are kept in place laterally by an angle-iron, 3 in. by 3 in. in section, riveted on each outer edge. The bolt-holes are deeply countersunk, and the holes filled with green-heart plugs, set in marine glue. The passing of these bolts through the vertical diaphragm-plates, and the difficulty of keeping them well tightened up, has been the source of some leakage into the gates, and even now occasionally gives trouble.

The attachments of the chain, for opening and shutting the gates, consist of strong gusset-pieces, riveted to the outside plating, so as to take hold of one of the horizontal diaphragms. Strong bolts are passed completely through the width of the gate, so as to bring the strain as much as possible on both skins. These attachments are also placed opposite each other, one on the inside and the other on the outside of the gate, so that the bolts pass from one to the other. In the lower gates they are at a height of 12 ft. above the sill, so as to be accessible at low water. The sectional diameter of the eye-bolt is 2¼ in., that of the opening and closing chain is 1¼ in., and the greatest strain brought upon them by the hydraulic machinery is about 7 tons per inch.

The footpath platform at the top, which is 3 ft. 6 in. wide in the middle, and 2 ft. 6 in. at the



2469.

2471.

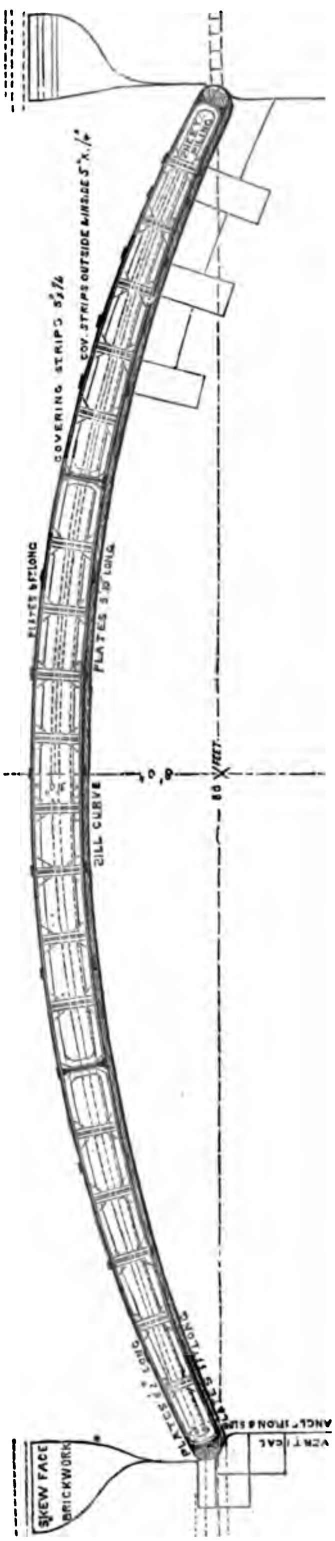
2472.

ends, consists of planking 3 in. thick, carried on cast-iron brackets, so as to be level with the coping of the wharf. The movable hand-railing on the side is 3 ft. high. Owing to the great curvature of the gates, a somewhat peculiar arrangement was necessary. In lock entrances generally, in consequence of the inconvenience and obstruction to the passage of ropes during docking hours, occasioned by the use of a fixed hand-railing, or fence, the standards have been usually connected by chains, and placed in sockets, so as to be easily taken out. This is an inconvenient method, and causes delay, from the number of separate parts, by encumbering the footway of the gates when down, and forming when up but an inefficient protection. In a recent example, the Hartlepool gates, which are straight, a rigid top rail was employed, connected by a knuckle-joint to the standards, which were jointed near the bottom, in such a way that the whole could be depressed, the top rail being parallel to the planking, and raised but a few inches above it. In the Victoria Dock gates, owing to the curvature, the standards cannot move in the same plane; they are therefore each made with a separate foot, in which they turn, as on a pivot, forming a swivel-joint. Above this is the lower hinge, and the top of the standard is connected with the top railing by a knuckle-joint, the railing being made of iron tubes 1¼ in. in diameter, bent to the form of the gate. Each standard has a counter-balance weight, which works by a short arm below the planking, out of the way, and the railing can be readily depressed to within 6 in. of the coping level, and be raised again, by one man. When down, the curved extremity of the railing lies on the wharf, and ropes, being prevented from getting under it, rise and slide along the smooth rail, thus avoiding any entanglement or obstruction. When raised the rail is kept up by a simple catch, which is easily released by the pressure of the foot. This railing forms a rigid and efficient fence.

The points of support, and the mode of retaining the gates in place, must now be described. These comprise, the pivot-cross, pivot and step piece, containing the pivot-brass, the shutting sill, roller and anchor.

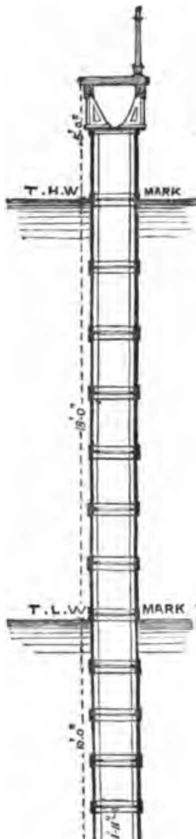
Pivot-Cross and the Pivot.—The foundation for the pivot consists of a massive cast-iron cross, the length of each of the four arms being 5 ft. from the centre of the pivot. These arms, which are hollow, are 18 in. square in section, and the metal is 2 in. thick, leaving an internal cavity 14 in. square. Strong oak timbers, 15 ft. long, are driven into these arms, projecting 10 ft. beyond the ends of the cast-iron cross. Through two of these timbers, four bolts, 2 in. in diameter, are passed down to two holding-down plates, which are 4 ft. square each, and are set in the solid brickwork. Between the arms of the cross, webs were cast, forming, with the included arms, an area of 16 sq. ft. Four bolts, each 2½ in. in diameter, connect the web to a massive holding-down plate, 5 ft. square, also bedded 8 ft. in the solid work below. The pivot-cross is placed with its arms parallel and perpendicular to the lock wall, which stands on two of them; the other two, the upper surfaces of which are on a level with the bottom of the shutting sill, are held down by the plates and bolts, as already described. On the upper surface of the cross, projections were made for attaching the first length of the shutting sill; and exactly in the centre, a circular fillet was left, which was accurately turned out, for the reception of the pivot, which is of cast iron, 6 in. in height, accurately turned to a diameter of 11 in., in order to work properly in the brass of the step-piece. The lower rim is also turned, to fit the recess in the pivot-casting. The upper step-piece is a casting 1 ft. 5 in. in depth, and about 5 ft. 8 in. long, strongly bolted to the under-side of the gate. It contains a recess for the reception of the brass, which is 16 in. long, 16 in. wide, and 5 in. deep. The sides of the recess are 2 in. thick, and the brass is accurately fitted, by means of chipping pieces and planing. A space was also left for end play, to prevent any strain being brought upon the pivot by the wearing away of the timber heel-post.

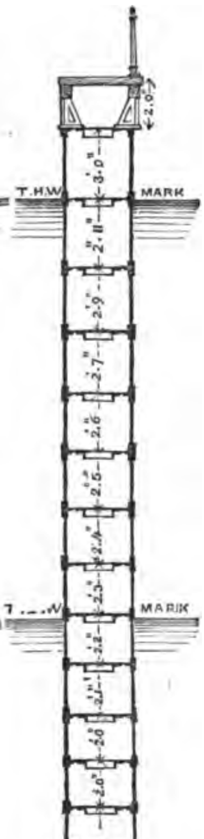
2470. Plan.



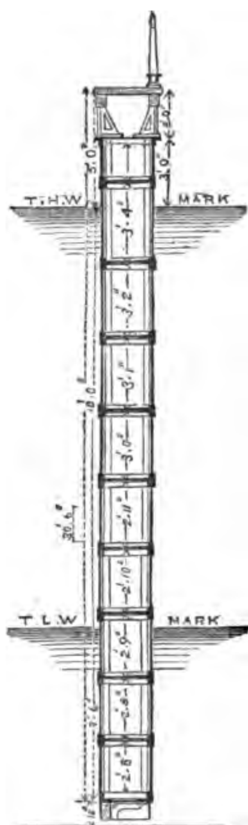
The Shutting Sill.—The shutting sill, the outer curves of which correspond to those of the inner curves of the gates, is composed of eight cast-iron segments, four on each side of the mitre-point. Its cross-section is in the form of an angle-iron, 12 in. high, 18 in. on the bed, and 2 in. in thickness. This is at the mitre or meeting point of the gates, and it gradually increases in height to 1 ft. 9 in., and in breadth to 2 ft. 3 in., respectively, where it is bolted to the pivot-cross. Each segment is strengthened by feathers, or gusset-pieces, at the back, at intervals of 2 ft. Chipping pieces are provided on all the junction surfaces, to ensure accuracy in fitting. The sill was secured by building into the brickwork, at a distance of 8 ft. beneath it, a strong cast-iron bed-plate, of the same area as the sill, through which bolts were placed and built in, leaving a small space round each other of them for adjustment. When the brickwork was brought up to the proper level, the sill was lowered down over the bolts, which were tightened up from time to time, and the spaces round them then grouted with cement. There are fifteen of these bolts for each segment, ten being 2 in. in diameter, and five of $1\frac{1}{2}$ in. in diameter, the larger bolts being placed as near as possible to the inside of the vertical face of the sill. As soon as the bolts were sufficiently tightened, the brickwork was carried up to the level of the top of the sill, over the area not traversed by the gates.

2473. 2474.
Sections of Lower Gates.

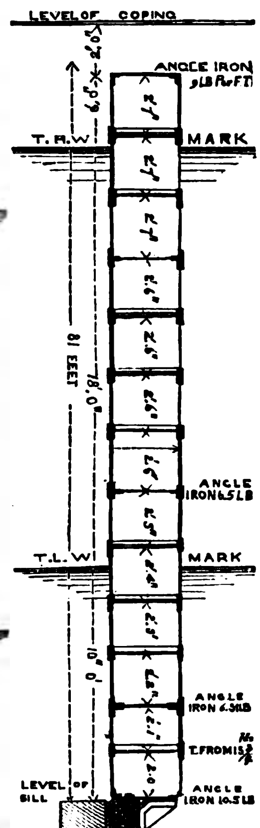




2475.
Section of Upper Gate.



2476.
Section of Caisson.



The Roller.—In the case of a gate with one roller, in order that it may work easily and bring as little strain as possible on the anchor strap, the axis of the roller must be in the vertical plane passing through the pivot axis and the centre of gravity of the gate, Fig. 2469. If the weight is to be distributed on the pivot and roller in a given ratio, the centre of gravity must lie between them, so as to divide the distance inversely in that ratio. This, in the case of a straight gate, would allow the roller to be placed under some part of the gate itself; but in a curved gate, especially when the curvature is considerable, such a position would in most cases throw an undue proportion of weight on the roller. Hence, in the present instance, it was so placed as to be wholly external to the outer curve of the gate. This, however, is advantageous, as it affords great facility for removing the roller for examination or repair without having recourse to diving apparatus.

The roller is a heavy cast-iron wheel, 7 in. wide and 2 ft. 8 in. in diameter, working in gun-

metal gudgeons of large dimensions, and kept in position by a framing of cast iron. This framing has at the top a hollow socket, which receives a step-piece, keyed into the bottom of a hollow column of cast iron, 12 in. in diameter and 23 ft. 7 in. long, and reaching nearly to the top of the gate. At its upper end this column is surmounted by a powerful screw, on which is placed a massive brass nut, working through a wrought-iron cross-head, by means of a capstan, which can be removed when it is not wanted. This cross-head is held down by four bolts, which are flattened out into straps, and are riveted against vertical pieces of wrought-iron plate, forming the sides of the roller-frame. These plates are connected with the whole depth of the gate by means of angle-irons and gusset-pieces. At the bottom they are carried up in a circular form to a height of about 6 ft., so as to enclose the roller ard protect it from injury. Within this, on each side, two brass guides are riveted to the wrought-iron-plate sides, and are carried up (in the case of the lower gates) above low-water mark. The distance between these guides is the width of the roller-frame casting. They open out into a trumpet shape near the top, and form a kind of groove, in which the roller-frame can slide, thus securing it from lateral movement when at the bottom. With this arrangement, the roller can be easily removed; for the gates being closed, it is only necessary to turn back the brass nut at the top, by means of the capstan, so as to allow the cast-iron column to be lifted the requisite height of 2 or 3 in., to clear the step-piece at the bottom. The column can then be slung on the outside of the gate, and the roller-frame casting, with the roller, can be drawn up the groove, by means of chains attached to it for the purpose. When clear of the guides, it can be lowered into a boat, or be hoisted on the lock wall; and after examination, it can be replaced with equal facility.

The roller-path is of cast iron, in the form of a bridge rail, 4½ in. wide and 8 in. high. The flat sole, or bottom flange, which is 15 in. wide, rests on a sill of iron-bark timber; bolts are passed through both, down to cast-iron plates, 3 ft. long and 2 ft. wide, set in the brickwork. One of these plates is placed under each joint in the path, and another in the middle of each length. The path and roller were designed for a working load of from 12 to 15 tons. The destructive effects of a much greater pressure, to which they were subjected for some time, will be alluded to hereafter.

The Anchor, see p. 60.

Having completed the description of the lower gates, it may be desirable to point out wherein the gates differ from each other.

It has been stated that the lower gates are 31 ft. high; and as the sills of the upper and the inner gates are 2 ft. 6 in. higher than the lower sill, these gates are 2 ft. 6 in. shorter, or 28 ft. 6 in. in height. Consequently, the outer skins were made somewhat lighter, and the horizontal diaphragms were fewer in number. In other respects the gates are almost identical, with two exceptions, which remain to be noticed. First, the inner gates are not worked by hydraulic power; and secondly, sluice-pipes are not employed, but the sluicing is effected through the gates themselves. These sluices are rectangular, 6 ft. wide, and with a lift of 2 ft.; and there are four in each leaf of the gates. They are worked in pairs, from the top of the gate, by racks and pinions; the racks being hung on opposite sides of each pinion so as to balance the weights, and to open the sluices by raising the one and depressing the other.

In concluding this portion of the subject, a concise summary of the weights of wrought and cast iron work in the gates is appended.

	Tons.
Wrought iron in the lower gates, including the cast-iron pivot step-piece	198
Ditto in the upper gates	128
Ditto in the inner gates, including the sluices	138
Cast iron in the shutting sills, pivot-crosses, anchors, rollers, roller-paths, foundation-plates, &c., and bolts for each pair of gates	59

The Caisson, Fig. 2474.—It has been mentioned, in an early part of this article that the ancient river wall or bank, which is about 5 ft. above Trinity high-water mark, protects the marsh from the overflow of the river, which rises considerably above the level of the district. This bank, therefore, formed a natural dam, behind which the formation of the inner works of the lock-chamber, the brickwork of the gates, and the other operations could be carried on; and outside of which a considerable portion of the piling and concrete walling could be executed. But in order to effect the junction of the two portions and to complete the entrance works, it was necessary to remove a large quantity of material. This was done first by barrow work, and then, below low-water mark, by the more tedious operation of dredging. In order that this excavation might proceed simultaneously with the other dock works, it was essential to provide the means for keeping the water out of the dock at the time when the river bank was being broken into and carried away. Owing to the great width of the entrance, considerable expense and delay would have occurred had a coffer-dam been employed, and recourse was therefore had to a caisson. But this differed considerably in form from those in general use, and was not employed or handled in the same manner. The usual form of a caisson somewhat resembles that of a ship, having inclined stem and stern posts, which fit into grooves in the side walls, whilst the keel applies itself at the same time closely against a shutting sill. The new caisson, Fig. 2476, which was made of wrought-iron plates, is rectangular in side elevation, the heel-posts being vertical and shaped like those of the gates, so as to fit into a hollow quoin as into a kind of rebate. In plan it is like one leaf of the gates, being 3 ft. wide in the middle and 2 ft. at each end; but it is large enough to extend across the span of 80 ft. between the lock walls. Its curvature is not so great as that of the gates, having a rise or versed sine of only 8 ft. The outer and inner curves are struck from points in the axis line of the lock, with radii of 94 ft. 8 in., and 104 ft. respectively. The height is 31 ft., which is the same as that of the ironwork of the lower gates.

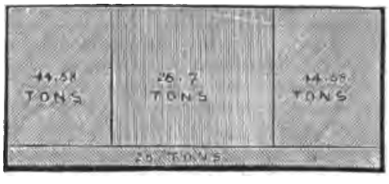
After the minute description already given of the gates, it will be unnecessary to enter into the same detail here, the general structural arrangements being similar in both cases. It may suffice

to state that there are but five horizontal diaphragms, of which two form the bottom and the top, and the three remaining ones are internal. The lowest of these is 4 ft. 1 in. above the bottom, the next 9 ft. 2 in. above that, then one 10 ft. higher up, leaving a space of 7 ft. 9 in. to the top plate. The position of the lowest inner diaphragm is not arbitrary or immaterial. It is placed at a distance of 4 ft. 1 in. from the bottom in order that the internal capacity or volume, comprised between the skins and the diaphragms, shall be equal to that of 25 tons of water. The object of this will appear presently. The diaphragms are connected by angle-irons, 3 in. by 3 in. in section, to the outer skins, which vary in thickness, from ½ in. at bottom to ¼ in. at the top. The lengths of the plates are disposed horizontally, differing in this respect from the gates. In width they increase regularly from 2 ft. at the bottom to 2 ft. 7 in. at the top. The internal horizontal joints, except where there are diaphragms, are covered by T-irons, weighing 13 lbs. per foot. The vertical end-joints are covered, both on the inside and on the outside, with strips. The T-irons are strutted across at intervals of 4 ft. by similar T-irons, triangular gusset-plates being introduced at the ends to give more rivet-hold and stiffness.

The caisson is also divided by two vertical diaphragms into three compartments, as in the case of a leaf of the gates. It has heel-posts like the gates, and a lining piece of creosoted Memel timber to meet the shutting sill. This timber, having to carry the weight of the caisson, is made of full scantling 15 in. square. It is also provided near the bottom with two rectangular sluices; one 3 ft. 9 in. long and 9 in. high, allowing the water to pass through the gate to fill the dock; and the other 10 in. square, opening on the concave side to admit water into the bottom compartment, already described as having a capacity for 25 tons of water. A three-throw pump, the working barrels being 4¾ in. in diameter and 12 in. stroke, is provided for emptying this compartment, and with the sluices is worked by gearing from the top.

The caisson quoins are of Duke's Quarry stone. They are placed in the brickwork of the side walls, where they begin to rake back from the perpendicular to meet the batter of the piling. The sill against which the timber liner shuts is of the same stone. The caisson itself rests on the heads of the piles which surround and enclose the brick platforms, and which are here driven in a curve corresponding to that of the caisson.

2477.



Showing the arrangement of the compartments of the Caisson.

In order to understand the working of the caisson, it is necessary to observe the distribution of the displacement spaces in the interior, Fig. 2477. The lower one of 25 tons has been already pointed out. Above this, the vertical diaphragms divide the remainder into three spaces, the middle one having a capacity for 25·7 tons of water, and the two outer ones for 44·68 tons each. Of these, the two last mentioned are kept empty. The middle one has apertures on the convex side so that water can freely enter the interior without passing through. The lower one is provided with special apparatus for filling or emptying at pleasure. The weight of the caisson being about 90 tons, if the water is pumped out of the bottom, the displacement will stand thus;—

	Tons.
Bottom	25·00
Right compartment	44·68
Left "	44·68
Total	114·36

This gives a floating power above the weight of the caisson of 24·36 tons, when it would float with the convex side downwards in a nearly horizontal position. If the small sluice was opened water would enter the bottom compartment, causing the caisson to tilt over, and gradually to assume a vertical position. During this time it could be drawn towards its place, and the heel-posts coming in contact with the quoins, the caisson could be guided into its proper position. If this operation was performed at the time of high tide, when there is a depth of 28 ft. of water on the sill, the lower compartment being full and the caisson in a vertical position, the displacement of the two side compartments would be diminished to 39·8 tons each, or 79·6 tons together; so that in this case the caisson would press the bottom with a load of 10·4 tons.

It will be seen that a caisson of this construction requires to get it out of its place only such a depth of water as will just float it, and as soon as it is free from the quoins it can be turned on its side, when it will present little surface to the wind, be quite stable in management, and not drawing more than 4 ft. water, can be readily moved from place to place.

In employing the caisson at the entrance to the Victoria Docks, the precaution was taken to put timber struts against the inside from sills bedded temporarily in the brickwork. A bed of clay puddle about 6 ft. high was also placed on the outside. No indication of weakness was observed, nor was there any leakage, the caisson doing its work perfectly. The greatest strain on the bottom section, with the entire head of 31 ft. of water, amounts to 86·5 tons per foot of depth, and such a sectional area is provided, exclusive of the bottom diaphragm, that the strain does not exceed 4¾ tons per square inch.

Casualties.—The casualties which occurred during the construction and subsequent to the opening of the docks, with the means adopted for remedying them and preventing their recurrence, will now be noticed.

Fracture of the Shutting Sill.—The earliest of these casualties, which was in fact but of minor importance, was the fracture of the shutting sill. The cast-iron shutting sill, as before stated, is

not only bolted down to foundation-plates, set in the brickwork, but is firmly connected, at each end, with the pivot-crosses, which are built into the heavy side walls. It will readily be inferred that the side walls, and with them the pivot-crosses, would settle to a greater extent than the comparatively light brick platform between them, and with it the corresponding portion of the sill. Such was found to be the case; for soon after the side walls were finished, the pivot-crosses were carried down about 1¼ in. on each side, while there was little or no subsidence of the sill in the centre. In consequence of this unequal pressure, the shutting sill was cracked about 3 ft. from the mitre; but the opening being very slight, the defect was readily repaired by bolting a plate of wrought iron at the back. This accident, slight as it is, points out the importance of guarding as much as possible against the effects of unequal loading, especially where cast iron is employed, in connection with brickwork or masonry. It suggests also the obvious expedient of allowing the side walls to settle before the holding-down bolts of the sill are finally tightened up.

Subsidence of the Side Walls of the Lock-Chamber.—This casualty was of a more serious character, involving the cast-iron and concrete walls of the lock-chamber. It occurred on Sunday, the 17th of June, 1855, at a period when great progress had been made with the works,—for the upper and lower gates had been lifted into their places, the caisson was nearly completed, the copings on the wharf were being laid, the bottom of the large dock was puddled, and, indeed, the removal of the river bank and the dredging at the entrance were the principal operations that remained to be done. There had been no symptoms of weakness, nor any premonition of what was about to take place, except that on the previous day some joints in the coping on the south side were observed to be a little open, but to so slight an extent that the circumstance was not reported. The next day, however, in the afternoon, the portion of the north side lying between the brickwork of the upper and lower gates began to give way, moving forward bodily into the lock, pushing up the thick puddle towards the centre, bending and breaking the tie-bars behind, and dragging the tie-piles forward, and in some instances breaking them off. A few hours afterwards the south side failed in the same way; but the brick side walls and platforms remained wholly unaffected, the most careful observation failing to discover any movement in them.

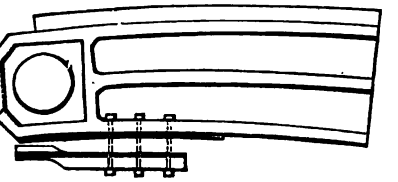
It being Sunday, some time elapsed before any men could be collected. They were first set to work to drag off the copings, and to lighten the earthwork behind. The most energetic measures were then adopted for reinstating the walls, and for this purpose the old concrete was cleared away from behind, and the iron piling was driven to a depth of 10 ft. lower than previously, the sheet-piles entering 5 ft. into the clay. A solid concrete wall was then commenced, at a depth of about 3 ft. in the clay, which was carried up for a height of 18 ft., with a thickness averaging 18 ft. Above this level, the thickness was reduced to 10 ft., with counterforts 6 ft. square at intervals of 10 ft. These counterforts were carried up nearly to the top of the piles. On this concrete wall there was built a brick wall, averaging 4 ft. 6 in. in thickness and 10 ft. high, with counterforts at the back 3 ft. square, corresponding in position to those of the concrete below. On the top of this wall the coping of the wharf was placed. The piles were tied back by the rods passing through the concrete and secured to cast-iron plates screwed up tight against the back of the concrete wall. The whole of the clay puddle in the bottom was taken out and replaced by concrete with a top layer of Portland cement concrete 6 in. in thickness. This work was completed by the 21st September following, or in a little more than three months. Considering the number of piles that had to be re-driven, and the quantity of material to be moved and replaced, it must be admitted that the work was expeditiously executed.

A failure, occurring so suddenly and on so large a scale, and appearing to be the result of an extended and powerful agency, demands some attempt at explanation. This will be better understood, after some preliminary observations. Ever since the commencement of the works, in the middle of the year 1853, the great pumps had been worked night and day. These were situated to the rear of the north wall of the lock-chamber, between the upper and lower gates, and at no great distance from them. They drained the water down to the level of the floor of the lock, the additional depth required for getting in the lower brickwork being kept free from water by means of a portable engine, lifting into the sump of the large pumps. As this operation had been going on uninterruptedly for two years, during which time a large excavation, to a depth of 16 ft. below the level of the marsh, was in progress, the surrounding country was gradually drained of its land water, for a considerable distance, in all directions. In corroboration of this remark, it may be stated that the water in a well situated in East Ham parish, more than two miles and a quarter from the docks in a direct line, was much lowered while the works were in progress, but it recovered its level when they were completed. At the time of the accident the pumping had been discontinued for some weeks, in order to allow water to collect in the dock to a depth of 3 ft., to test the clay puddle; but it was excluded from the lock-chamber by a temporary stank. It would result from the fact of the ground gradually recovering the charge of water which had been drained from it, that additional pressure would be brought upon the back of the lock walls, and under disadvantageous circumstances; for while, in ordinary cases, where there is a possibility of water collecting behind a wall, provision is made for letting it escape, here, from the nature of the case, this was impossible, and its effect was in consequence aggravated. The substitution of clay puddle for the gravel at the bottom, was to a certain extent an evil, as the walls were thereby deprived of weight at the foot, the tendency of which would have been to prevent forward motion. A further confirmation of the opinion that the failure resulted from the action of accumulated water, is suggested by the fact that the movement of the two sides was nearly simultaneous.

Fracture of the Pivot-Casting.—This occurred to two out of the four gates of the entrance lock, and it was some time before the true cause of the failure was discovered. This casting, which is bolted to the under-side of the gate, has been described as having a box, or recess, of an octagonal form, to contain the pivot-brass. It was found, in each case, that the same adjacent sides of the box had given way, namely, those between the brass and the hollow quoin, and between the brass

and the shutting sill respectively. It is also necessary to state that in fitting the heel and the mitre posts, it was considered desirable to make allowance for some shrinking and compression of the wood. Provision to the extent of $\frac{3}{16}$ of an inch, in the length of the two leaves, was therefore made; but experience showed that this was more than was required. As the mitre-post could not be easily reduced, so as to permit the timber sill to be brought into perfectly close contact with the iron one, a lining piece of thick flannel was secured to the former by copper nails, to make the joints water-tight. When the first fracture occurred, it was attributed to some irregular or undue thickness of this lining near the heel-post, or to the accidental interposition of a hard substance between the timber and the iron sills. A portion of the flannel was therefore removed, and diligent search was made for any iron bar, chain, hard wood, or stone, which might by possibility have occasioned the mischief, but without success. The broken box was repaired, as shown in Fig. 2478, by bolting on a cast-iron fish-piece to one of the side flanges of the pivot-piece, which was conveniently situated for the purpose. This operation of drilling three holes, $\frac{3}{4}$ of an inch in diameter, through a thickness of $2\frac{1}{2}$ in. of cast iron, under water, and of bolting on the fish-piece, was accomplished by a diver in about five hours.

2478.



Plan of the under-side of the pivot-piece, showing the cast-iron fish and the broken portions.

Notwithstanding every precaution, the fish-pieces were frequently broken, and it became evident that the true solution of the problem had not been discovered. The north upper gate having proved the most troublesome, and its pivot-casting having been further damaged by the use of a wrought-iron fish-piece, it was resolved to float the gate in order to investigate more closely and to replace the casting by a wrought-iron step-piece. From the appearance of the brass it was evident that it had been subjected to great pressure. In consequence of the radius of curvature of its internal surface having been erroneously made somewhat less than that of the pivot, the pressure, instead of being distributed over the whole area of the step, was found to be restricted to a comparatively small annular portion situated near its circumference. The corresponding surface of the brass may be considered as a portion of a hollow cone, which would aggravate the effect of the pressure according to the disparity of the two curvatures, the ultimate result being that the brass seized or adhered to the pivot to such an extent that the gate turned upon the brass instead of upon the pivot, breaking away the walls of the box in the effort to free itself. The great weight on the pivot is accounted for by the fact that, owing to the leakage through the bolt-holes of the heel and mitre posts, and through some portions of the gates, the calking of which was not complete at first, the gates were frequently nearly full of water. In the case of the lower gates, the points of support, namely, the pivot and the roller, were sustaining from 40 to 45 tons each, instead of 12 or 15 tons, the working load which each was intended to carry. The leakage was soon remedied, and the gates then having a proper amount of flotation, no fracture from this cause has since occurred.

It must be borne in mind that hydraulic machinery was employed from the first to open and shut the gates, and although a great additional power must have been required to open the gates when this seizing had taken place, a resistance represented by the force required to break down so large a section of cast iron, there were no ready means of measuring its amount or even of detecting its existence. If manual labour, at a crab, had been made use of, the resistance and the remedy would have been speedily discovered. It is, perhaps, worthy of consideration whether it would not be the most prudent course, in cases of this kind, to resort at the outset to a temporary expedient similar to the one alluded to, and when the true working *régime* has been ascertained to revert to the permanent arrangement.

There has been one instance of a fish-piece being fractured in consequence of a large fender, through carelessness, being lodged between the gate and the sill near the heel-post while the gates were being rapidly closed. To avoid such a contingency, the sill might be formed like an invert, the heel-posts being thereby raised several feet above the floor of the lock-chamber, then any obstruction calculated to do injury would have a tendency to fall towards the mitre-posts, where, if it were interposed between the gate and the shutting sill, it would be quite harmless.

Abrasion and Splitting of the Roller-Path.—This occurred at the lower gates only, and was a direct and intelligible result of the weight of the gates, caused by the leakage just mentioned, in consequence of which the load the path had to sustain was for a time three or four times the weight which it was intended to bear. The new path was made 7 in. instead of $4\frac{1}{2}$ in. in width, and in substituting this for the former one by means of divers, great facilities were afforded by the hard wood timber sill, for ensuring the accurate level and the adjustment of the several lengths.

On the Construction of the Jetties.—In the early part of this paper the jetties were incidentally noticed, and their number, situation, and general dimensions were briefly pointed out. It is now necessary to describe the mode of constructing the quay walls, and to give some other particulars relating to this portion of the works.

In general form, Figs. 2479 to 2483, each jetty is a parallelogram, 140 ft. in width for a length of 497 ft., and having a pointed or wedge-shaped termination, the sides of which are each 109 ft. 6 in. long, and inclined to one another at an angle of 80°. The total length of each jetty is 581 ft., and the level of the quay varies from 6 ft. to 9 ft. above Trinity high-water mark, according to the situation of the jetty in the dock.

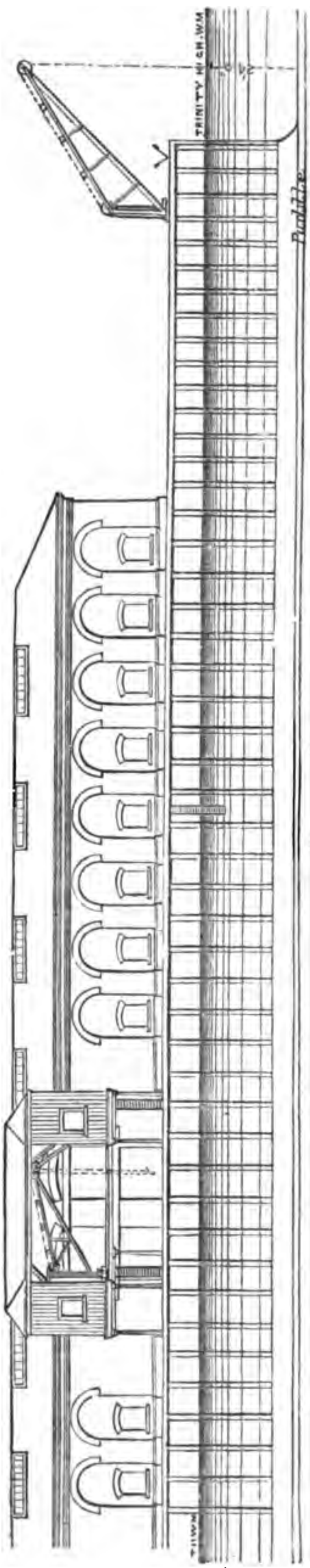
A warehouse, comprising an upper floor, ground floor, and vaults underneath, nearly approaching an acre in extent each, occupies a length of 500 ft. and a breadth of 80 ft. out of the entire width of the jetty, leaving a space 30 ft. wide on each side to the edge of the quay, for the railway, sidings, and the temporary storage of goods. In order to afford facilities for the discharge and arrangement of goods, each jetty is provided with nine hydraulic cranes. One, capable of lifting 5 tons, with a

range of 31 ft. beyond the quay, is placed at the pointed end, and eight others lifting 2 tons each are disposed in pairs at convenient distances along the sides. One crane of each pair is fixed near the edge of the quay, with a sweep outwards of from 21 to 23 ft., and the other is placed against the outside wall of the warehouse, for the purpose of removing goods to or from the upper floor or the vaults beneath as may be required. Sidings and turn-tables are also provided at the rear of the jetties, for the purpose of collecting or distributing the wagons on the line of railway leading to and from the docks.

The side walls, which are vertical, consist of cast-iron piles, driven 7 ft. apart from centre to centre, and upright inverted walls of brickwork, 14 in. thick, filled in between the piles, and set in Roman cement mortar. The concave surface of the invert, which has a versed sine of 12 in., is external, or in contact with the water of the dock; while the convex, or inner surface, is backed with concrete, and behind this with clay. The piles, which are T-shaped in section, are 35 ft. long, 12 in. wide on the face, and, averaging $1\frac{1}{2}$ in. thickness of metal, weigh about $1\frac{3}{4}$ ton each. They are connected, in pairs, across the width of 140 ft., by two tiers of horizontal tie-bars, 2 in. in diameter, and fixed to the back feathers of the piles, which are 18 in. deep, by means of eye-bolts furnished with a screw, by which the piles can be adjusted so as to be exactly in line. The upper and lower tie-bars are fixed at depths of 5 ft. and 17 ft. below the heads of the piles, which are thus prevented from being forced outward by the pressure of the earth behind them. The piles are driven to a depth of 28 ft. below Trinity high-water mark, entering the gravel 2 ft. below the clay-puddle lining of the dock, and, as this is 2 ft. thick, to a depth of 4 ft. below the finished surface of the bottom of the dock. The brickwork is commenced at a depth of 23 ft. below Trinity high-water mark, or 1 ft. above the bottom of the dock, and is laid on concrete 3 ft. in thickness. The concrete wall is carried up behind the brickwork, with an average thickness of 3 ft. 6 in. The back of the concrete wall is made straight and vertical, and against this the clay backing is filled in. The pointed extremity of the jetty is not formed with an angle-pile, but by filling one bay with curved cast-iron plates, backed with a mass of concrete. This not only serves the purpose of resisting the heavy blows to which this part of the work is exposed, but also forms a solid foundation for the 5-ton crane, which has been already mentioned. The top of the wall is covered with a cast-iron capping, bolted down to the heads of the piles, and finished off with a timber sill. The upper surface of the jetty, not occupied by the warehouse, is ballasted, and some portions of it, adjacent to the edge of the quay, is covered with planking. In order to prevent the passage of water from the dock under the walls, the clay puddle was brought up on the outside to a height of 5 or 6 ft. against the piles and brickwork, so as to fill up the angle formed by the vertical face with the floor of the dock.

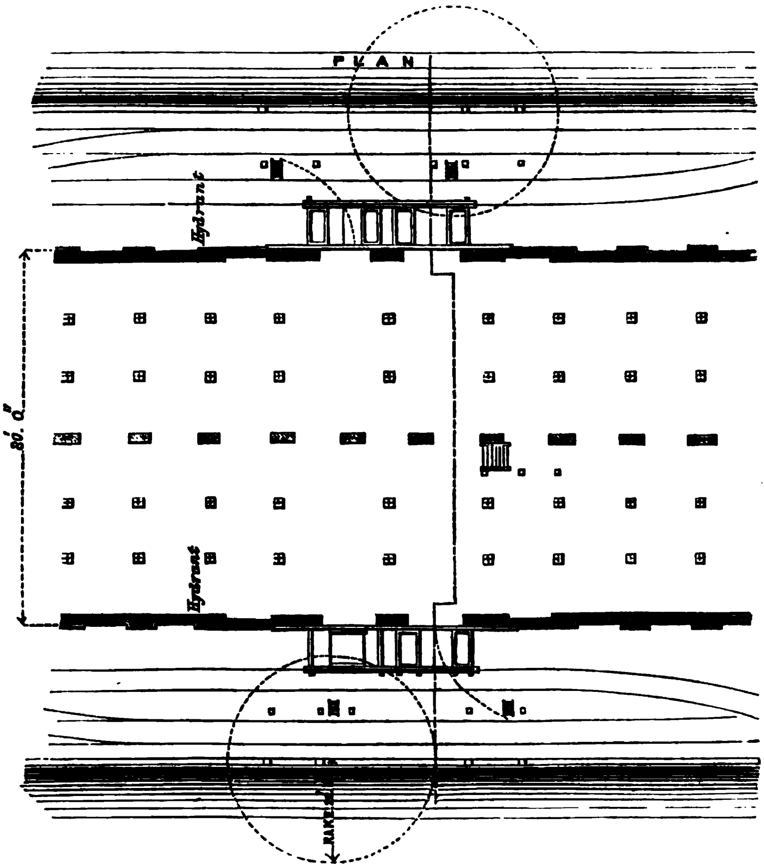
It may be interesting to notice a circumstance which occurred soon after the water had been let into the dock, and which appeared to indicate at the time that the walls were not impervious, notwithstanding the precautions taken to render them so. It will be observed, Fig. 2482, that the floor of the vaults under the warehouse is about 2 ft. 6 in. above the level of the marsh, and therefore 6 ft. below that of the water in the dock, when standing at Trinity high-water mark. It was found, soon after the water had risen to that level, that it appeared in the vaults to an extent which unfitted them for the purposes for which they were designed, the effect being aggravated at spring tides. It was thought that the water must have come from the dock, either by direct leakage through the walls, by passing under them, or down the piles into the gravel below, and thence upwards again into the vaults. In order to obviate the inconvenience arising from it, pipes were laid beneath the floors against the side walls as low as possible, but retaining a good fall into the marsh drain; and careful observations of the quantities of water discharged by them were made from time to time. It soon became evident, however, that the

2479.

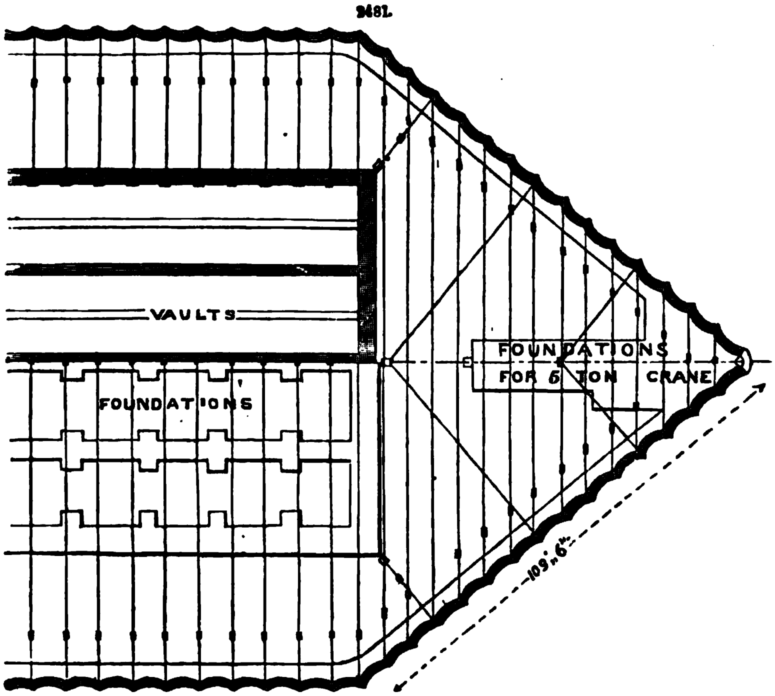


Elevation of Jetty.

2480.



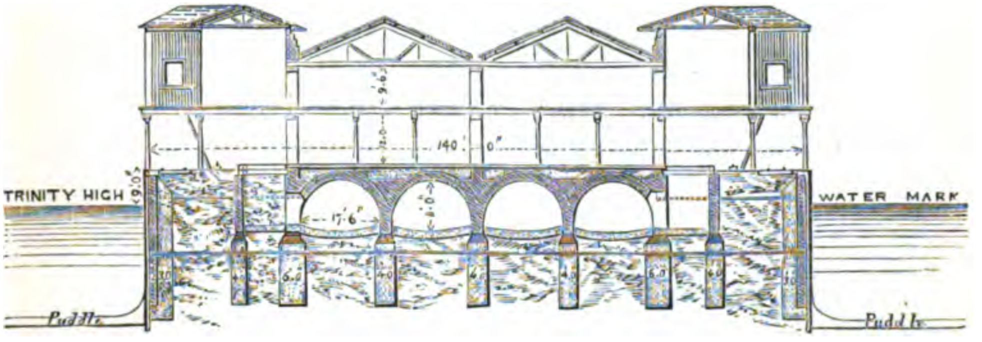
2481.



Sectional Plan.

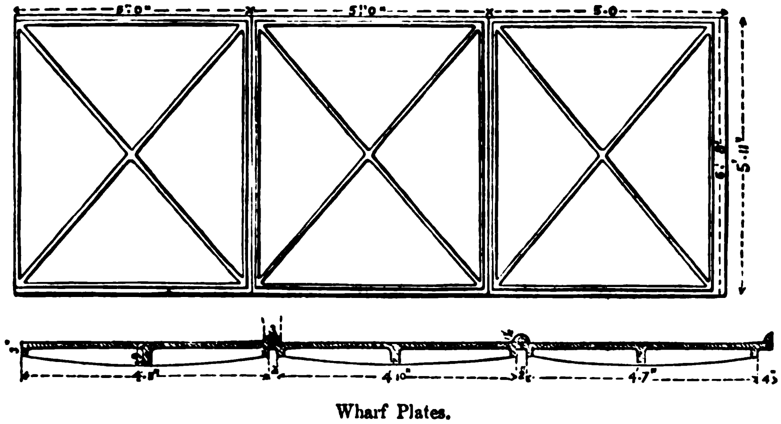
water differed in character from that of the dock, by its containing much iron, which was deposited in the form of a rusty mud at the mouths of the drains, and that the quantity sensibly diminished. From these facts it was inferred that the water came from the gravel, rising, on the discontinuance of the pumping, to the general level of the district, which experiments showed to be within a few inches of the surface. In the case of the vaults the water found its way up the concrete walls, which, resting on the gravel, formed the foundation of the walls of the warehouse. The discharge from the drains is now slight, and is apparently independent of the rise of tide. This is probably due, partly to the consolidation of the ground against the concrete walls, and partly to the gradual silting up of the porous materials by the rusty deposit. This explanation has recently received a singular confirmation from the fact that, while the foundations were being put in for a warehouse, which has just been erected on the level of the marsh on the north side, and the water-level in the excavation was temporarily lowered by pumping, no water escaped by the drain from a neighbouring jetty; but shortly after the pumping was discontinued the discharge from the vault was re-established.

2482.



Cross-section of Jetty on C D.

2483.



Wharf Plates.

Advantage of the Cylindrical Form of Lock Gates.—Some advantages of the cylindrical form of lock gates, or gates of continuous curvature, with respect to economy of material and arrangement of parts, will now be pointed out.

By the term "cylindrical gates or gates of continuous curvature," adopted for the purpose of distinguishing them from gates formed like a Gothic arch, a common and useful modification of the straight gates, it is intended to denote that the two leaves constituting the pair form a portion of a cylindrical ring, the outer or convex curve being the arc of a circle, extending from one heel-post to the other, and therefore continuous, while the inner curve is concentric with the former or nearly so. It is in the case of gates of large span that it is found advantageous to modify the form of the inner curve so as to reduce the thickness or distance between the skins of each leaf from its centre to the heel and mitre posts, in order to restrict the dimensions of the timber in these places. For this purpose two arcs are struck, one for each leaf, from centres which are near to each other, and with radii, which, while giving the proper thickness in the middle, secure, at the same time, the required diminution towards the ends. In this case, therefore, the inner curves would form a slight angle or mitre. In comparing this mode of construction with that of the straight-leaved gates, meeting at an angle, it is not intended to claim any advantage, either with regard to the amount of the strain brought upon the lock walls, or to the direction of it; for with the same rise and span the amount and direction of this thrust will be the same. This is not the case with the sections, and consequently the weights of the gates: for a considerable, not to say enormous saving, will be

found in favour of the cylindrical form of gate, even within the limits of the ratios of rise to span, assigned by every-day experience.

Before proceeding to exhibit this saving by actual examples, and in a numerical form, a few remarks on the strains to which these structures are exposed, and the mode of calculating them, will be advisable. In the case of the cylindrical gate, the pressure of the water being supposed to act on the convex side will be proportional to the depth, and in a direction normal to the surface. It will induce a strain on the gate wholly compressive, so long as it retains its true form, and it will be uniform on every radial section in the same horizontal plane. The amount of this strain has been shown by Barlow to be the pressure on the unit of surface, multiplied by the radius of curvature. This affords an easy method of calculating the section required to resist this strain at any given depth.

In the case of straight gates, however, there are two distinct strains to be considered; first, a transverse strain, arising from the pressure of the water at right angles to the surface, and similar to that on a girder uniformly loaded; and secondly, a compressive strain in the direction of its length, produced by the pressure of the other leaf on its extremity.

The transverse strain may be considered to arise from a central pressure, equal to half the distributed pressure on the leaf, and calculated as in the case of a girder; while the compressive strain is equal to this central pressure, multiplied by the cotangent of the angle between the gate and the chord line, at the heel-post, or by the tangent of half the angle at the vertex. Hence, if the angle at the vertex is 90°, the compressive strain is equal to the central pressure on the opposite leaf; if the angle is about 127°, or the ratio of the rise to the span is 1 to 4, as in the gates of the Victoria Docks, the compression is twice the central pressure; while in an extreme case, though an actual example, that of the ancient lock of Sparndam, where the angle is about 165½°, and the rise is $\frac{1}{16}$ of the span, the compressive strain is eight times the central pressure, or four times the total pressure, distributed over the opposite leaf. In calculating the strength of straight gates, a section must be provided, which is sufficient not merely to resist the compressing and extending strains brought on the outside and inside skins respectively by the pressure of the water, but also the compressive strain due to the other leaf, a strain which has been shown to be considerable in amount, even in cases falling under ordinary observation.

The next consideration is how and in what proportion the compressive strain due to one leaf is distributed through the skins. This, it is evident, cannot be determined accurately, for while on the one hand the effect of deflection might be to relieve the outer skin of a portion of its share of the work; on the other hand, the action of the hollow quoin, and the practice of making the joint of the meeting posts tight at the shutting sill and easing it upwards, would tend to increase the duty on the outer skin. It may be sufficient for the present purpose to assume that it is equally divided, half going to increase the compressive strain on the outer skin, and half to counteract or neutralize the extension strain of the inner skin, an assumption which, at any rate, is in favour of the straight gate.

For the purpose of comparing the quantity of material required under the two modes of construction for accomplishing the same object, it will be convenient to take three cases;—

First, that in which the ratio of the height or the versed sine to the span is small, say 1 to 10.

Second, that in which the ratio is intermediate between the extremes, say 1 to 6.

Third, that in which the ratio is large, say 1 to 4, as in the case of the gates of the Victoria Docks.

Since the pressure of the water varies with the depth, it will be convenient in every case to consider a portion or element of the gate only bounded by two horizontal planes 1 ft. apart, and immersed at such a depth that the pressure per unit of surface = 1, say 1 ton a square foot. In each case the span will be taken as equal to 80 ft., and the thickness of the gate, or distance between the skins, as 3 ft.

In the first example, that of the straight gate, the rise being $\frac{1}{10}$ of the span, or equal to 8 ft., the transverse strain in the centre of one leaf due to the pressure upon it will be 6·39 tons, either of compression or extension. Consequently, the section to be provided, allowing 4 tons to the square inch for compression, and 5 tons per inch for extension, must be

$$\frac{69\cdot 3}{4} = 17\cdot 3 \text{ sq. in. on the compressed side.}$$

$$\frac{69\cdot 3}{5} = 13\cdot 8 \quad \text{,,} \qquad \text{extended side.}$$

In this case the tangent of the half angle at the vertex is 5; hence the compressive strain is twice and a half the distributed pressure on the other leaf, or $40\cdot 78 \times 2\frac{1}{2} = 102$ tons. Then adding half of this, or 51, to the 69·3 representing the compression due to transverse strain, and deducting it from the same quantity, representing the extension due to the same strain, two quantities result, namely, $\left.\begin{matrix}120\cdot 3\\ 18\cdot 3\end{matrix}\right\}$ which divided respectively by $\left\{\begin{matrix}4\\ 5\end{matrix}\right.$ give $\left.\begin{matrix}30\cdot 1\\ 3\cdot 7\end{matrix}\right\}$ for the areas of the compressed and extended sides respectively, making in the aggregate 33·8 sq. in. centre section. It must be remarked that this assumption, that half the compression may be regarded as counteracting the extension on the inner or extended side of the gate, could not in all cases with prudence be acted upon, for in many instances the thickness of the plates would be reduced to an impracticable extent or so as to induce other inconveniences. It is a question whether the whole of the compressive strain may not at times be borne by the compressed section, and if so a much larger aggregate section than that stated above would be required, in fact it would entail an addition of nearly 70 per cent. The truth probably lies between the two. At the present time, that assumption is employed which is most favourable to the straight gate; and the wide difference in the results, according to the view taken, is stated as another illustration of the great importance of taking this

compressive strain into account, in calculating the section and consequently the weight required. The section just obtained is the centre or maximum section. Before a correct comparison can be made with the cylindrical gate, the mean section must be arrived at. To do this it must be recollected that at the ends, where in a girder, speaking theoretically, the section of the flanges is vanishing, a lock gate must always have section enough to resist this compressive strain, and so of every other section. Hence, if 102 tons be the compressive strain, and reckoning 4 tons per square inch, there must be 25·5 sq. in., which with a centre section of 33·8 will give a mean section of $\frac{33 \cdot 8 + 25 \cdot 5}{2} = 29 \cdot 6$ sq. in. This multiplied by the length 40·78 of the gate = 1207, which represents the quantity of material, or weight in the element, or portion under consideration.

In the cylindrical gate the mean section can be calculated from the compressive strain, which is equal to the pressure per unit of surface (in this case, as in the former, taken at 1 ton a square foot) multiplied by the radius of curvature. The radius of curvature for the arc of a circle whose height is 8 ft., and base or chord line 80 ft., is 104 ft., and reckoning 4 tons an inch for compression, the section required is $\frac{104}{4} = 26$ in., which is also the mean section. This multiplied by 41·02, the length of the arc representing one leaf = 1066, which represents the quantity of material or weight in the element of the leaf.

The quantities, therefore, stand thus;—

1207 in the straight gate,
1066 in the cylindrical gate,

the latter exhibiting a saving of more than 11½ per cent.

In this case the ratio of the height or the versed sine to the span is small, and is less favourable to the cylindrical gate than in the following examples. The calculation is given with some detail, that the mode of conducting it and the assumptions may be clearly understood; but as the same method has been followed in the succeeding cases, the results may be more summarily stated.

In the second example, in which the ratio of the height to the span is 1 to 6, the span being 80 ft., the height 13·3 ft., and the thickness of the gate, or the distance between the skins, 3 ft., there is in the straight gate a transverse strain in the middle of 74·06, and a compressive strain of 63·25, requiring a mean section of 25·35 sq. in., the compressive strain being supposed to be equally distributed in the two skins. Then 25·35 multiplied by 42·16, the length of the leaf, gives 1069, which represents the quantity of material as before. In the cylindrical gate, the radius of curvature being 66·66 ft., the mean section is 16·66 sq. in., which, multiplied by 42·89, the length of the arc, gives 715, representing the quantity of material. The quantities, therefore, are 1069 in the straight gate, and 715 in the cylindrical gate, the latter showing a saving of 33 per cent.

In the third example, in which the ratio of the height to the span is 1 to 4, as in the gates of the Victoria Docks, the span being 80 ft., the height 20 ft., and the thickness of the gate, as before, 3 ft.; there is in the straight gate a transverse strain in the middle of 83, and a compressive strain of 44·7, requiring a mean section of 24·8 sq. in., which, multiplied by 44·7 the length of the leaf, gives 1117 to represent the quantity of material. In the cylindrical gate the radius of curvature being 50 ft., the mean section is 12·5 sq. in., which, multiplied by 46·36, the length of the arc, gives 580 to represent the quantity of material. The quantities, therefore, are 1117 in the straight gate, and 580 in the cylindrical gate, exhibiting a saving of 48 per cent.

The following Table contains several additional examples, and exhibits a tolerably complete comparison of the quantities under the two points of view, through a progressive change in the ratios from 1 to 10, 1 to 9, and so on, to 1 to 2·66.

Ratio Rise to Span.	Vertical Angle.	Transverse Strain in the Centre.	Compressive Strain due to Opposite Leaf.	Straight Gate.		Cylindrical Gate.	
				Mean Section.	Quantity of Material.	Mean Section.	Quantity of Material.
	° ′						
1 to 10	157 22	69·32	102	29·6	1207	26	1066
,, 9	154 58	69·94	92·3	28·4	1164	23·6	975
,, 8	151 26	70·82	82·5	27·25	1123	21·25	885
,, 7	148 10	72·08	72·9	26·25	1092	19	801
,, 6	143 8	74·06	63·3	25·3	1069	16·66	715
,, 5	136 24	77·32	53·8	24·8	1011	14·5	640
,, 4	126 52	83·33	44·7	24·9	1117	12·5	580
,, 3	112 38	96·27	36	26	1250	10·8	552
,, 2·66	106 16	104·15	33·3	28	1400	10·4	558

It also shows that this quantity reaches its minimum value in the straight gate when the vertical angle is about 136°, and in the cylindrical gate when the angle is about 112°, corresponding to the ratio of 1 to 3. A still more important fact is, that the absolute minima in the two cases differ so considerably that, if the quantity in the straight gate at that limit be represented by unity, the quantity in the cylindrical gate, at its minimum, descends to one-half or thereabout.

It is to be observed that, in calculating the mean section of the straight gate, no allowance has been made for loss of area by rivet-holes on the extended side, and since, in order to ensure the close fitting of the plates to render the gates water-tight, the rivets must be placed closer together than in ordinary girder-work, a larger provision for cover plates should be made than is usual, the

difference, whatever it amounts to, being wholly in favour of the cylindrical gate. Again, the horizontal diaphragms, which correspond to the middle web in a girder, form a large percentage of the entire weight of the gates, amounting to 17 per cent. of the gates of the Victoria Docks. In the case of the straight gate, considered as a girder, it is the practice to neglect the middle web in calculating the sections; but in that of the cylindrical gate, where the strain is compressive, the area of the horizontal diaphragms is clearly admissible, and results in a large advantage if properly constructed with a view to this duty. Some advantage might also be claimed for the arched form of the skin plates in resisting pressure, as compared with perfectly flat plates; but as the determination of the strain on the latter due to this is not a simple problem, it will suffice to draw attention to the circumstance in general terms.

In the course of the foregoing description of the gates of the Victoria Docks, allusion has been incidentally made to another practical advantage of this form in affording greater facility for removing the roller, in consequence of its external position. In a straight gate this would not be so conveniently effected, because its proper position is under the gate, and its diameter would also be thereby somewhat restricted; while, on the other hand, the straight gate possesses the advantage of permitting a longer shaft to be made use of.

But a still greater practical advantage, and, next to the saving of material, the most important one arising out of the cylindrical form, is the uniform thickness of plates in the same horizontal section. This, of course, is in consequence of the uniform compressive strain on the radial section. If the comparison were between two girders only, one having plates thicker in the middle than at the ends, and the other with a uniform thickness throughout the length, there would not be so much to remark upon it. It is true that in the case of the girder with bottom or top plates of unequal thickness, good workmanship requires the insertion of packing strips to ensure the even bedding of the angle-irons, but in lock gates the skins and diaphragms have to be put together so as to be water-tight, and every joint has for this purpose to be covered with strips and to be calked. Practical men well know how difficult it is to accomplish this when plates of different thicknesses come together. As the pressure upon the gate and, consequently, the section required, diminishes from the bottom upwards, the plates are necessarily reduced in thickness in a vertical direction, but they remain constant in the same horizontal plane when disposed in the manner shown in the caisson. Hence the difficulty alluded to has to be contended with in one direction only, and can be effectually overcome. But in straight gates it becomes serious, and is further complicated with the cover plates on the extended side, which would be converted into a species of very wide covering strips running in a vertical direction up the gate, and by their thickness unduly adding to the weight and to the risk of imperfect jointing.

It must not, however, be concluded that the inconveniences of the cylindrical mode of construction have been lost sight of. No doubt the curved work entails additional cost in the manufacture, and should only be entrusted to contractors of experience and reputation. It also to a certain, but not to a large extent, diminishes the surface of heel-post in contact with the hollow quoin. It likewise, from the curved form and depth of the gate-recess in the side walls, somewhat breaks the quay line, and, where the curvature is considerable, renders the application of fenders desirable to prevent the concave side of the opened gates from being run into. Most of these are, after all, insignificant objections. The first, the cost of workmanship, is more than abundantly covered, by the great saving in material shown by even the most unfavourable example.

The Tyne Docks at South Shields.—The account that we give of these important docks is taken from a paper by T. E. Harrison, given in the Minutes of the Proceedings of the I. C. E., 3rd May, 1859.

The docks are constructed on the banks of the river Tyne, at the upper end of South Shields, on a large area called Jarrow Slake, which is covered with water at spring tides to a depth of from 5 ft. to 8 ft., Fig. 2484. The whole area of this slake, so covered, was about 350 acres, and of this quantity, 179 acres are now enclosed by the works of the docks.

The area of water in the dock, as executed, is 50 acres, the depth of the water being 24 ft. 6 in. at an average spring tide. The entrance basin is 9¼ acres in extent, with a depth of water of 25 ft. for a width of 200 ft. in the centre of the channel, gradually shoaling to the sides. There is one entrance 80 ft. in width in the clear, and there is a lock 300 ft. long by 100 ft. wide, with gates 60 ft. in width in the clear; the sills in each case are laid 24 ft. 6 in. below high water of an average spring tide; such spring tides having a lift of 14 ft. 6 in. Figs. 2485, 2486, and Figs. 2489 to 2493, show these arrangements, and also sections of the locks. From accurate observations taken at each tide for two years, it appears that there would only be sixteen days in the year in which a vessel, drawing 20 ft. of water, could not go out.

The contract for the execution of the whole of the works, as designed by T. E. Harrison, the engineer-in-chief, was let to James Gow in June, 1855. The works were commenced in July, 1855. The foundation-stone of the masonry of the locks was laid in September, 1856; and the water was let into the docks in December, 1858. The first vessel entered in January, 1859, and the docks were formally opened for general traffic on the 3rd of March, 1859. The works were executed under the immediate superintendence of Robert Hodgson, resident engineer.

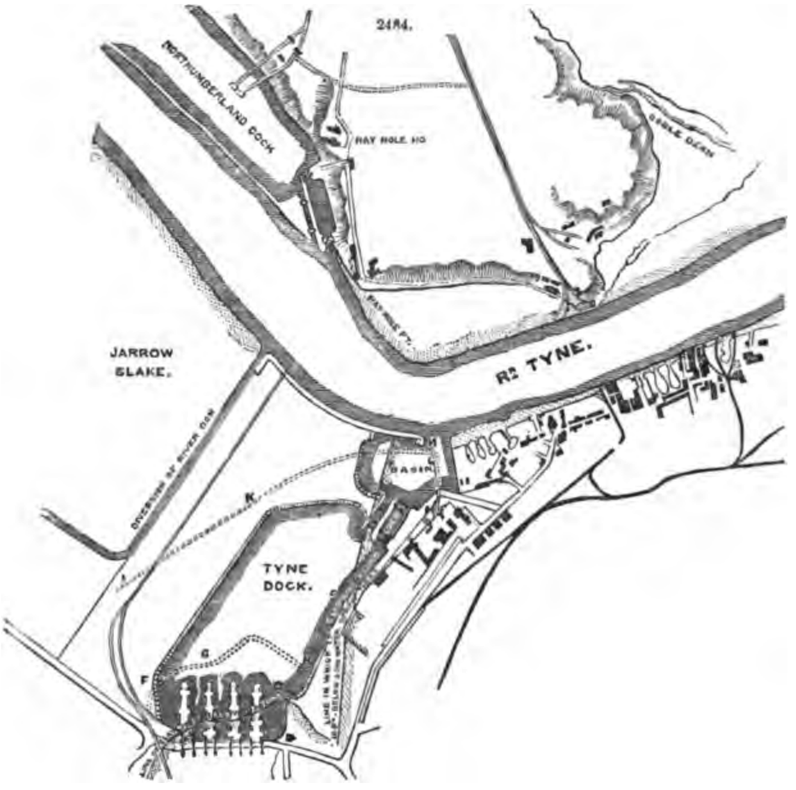
The total quantity of excavation in the docks was 1,783,452 cub. yds., and in forming the standage ground 281,305 cub. yds. The total quantity of masonry of all descriptions was 2,900,000 cub. ft. The whole cost of the works up to the date of the opening for public traffic was 440,479*l*. 9*s*. 8*d*. This sum included all the standage and railway approaches, the shipping jetties, the purchase of land, and all the dock works, but it excluded parliamentary and other charges, exclusive of engineering.

The first point of engineering interest is the nature of the foundations. A series of careful borings showed that though there was in places a very strong stony clay resting on the coal-measures, yet that this clay was only partial, and that it dipped suddenly away. Within a few yards of the clay bed, borings were made to a depth in some places of 70 ft. and upwards, through

the mud or slake deposit, without reaching a solid bottom, showing that not only the clay but the coal-measures were gone.

The first operation in the construction of the works was to form a large culvert, 5 ft. in diameter, round the head of the works. This served to keep the works clear of upland water during their execution, and will permanently carry off all the land waters. The bank F G H, Fig. 2484, was then formed, and a small portion of the upper end of the slake was thus enclosed. With the material excavated from this portion of the work, which was partly clay and partly slake, and also with the clay excavated in forming the standage ground above, the bank I K L was formed to meet the dam M N run out from the alkali-works. This dam had also a temporary timber jetty, fitted with steam-cranes, and lines of railway on it, to enable the Jarrow Chemical Company to carry on their works during the construction of the docks. After these dams were completed, the water was run off by sluices, and no difficulty was experienced from water during the execution of the works.

2484.

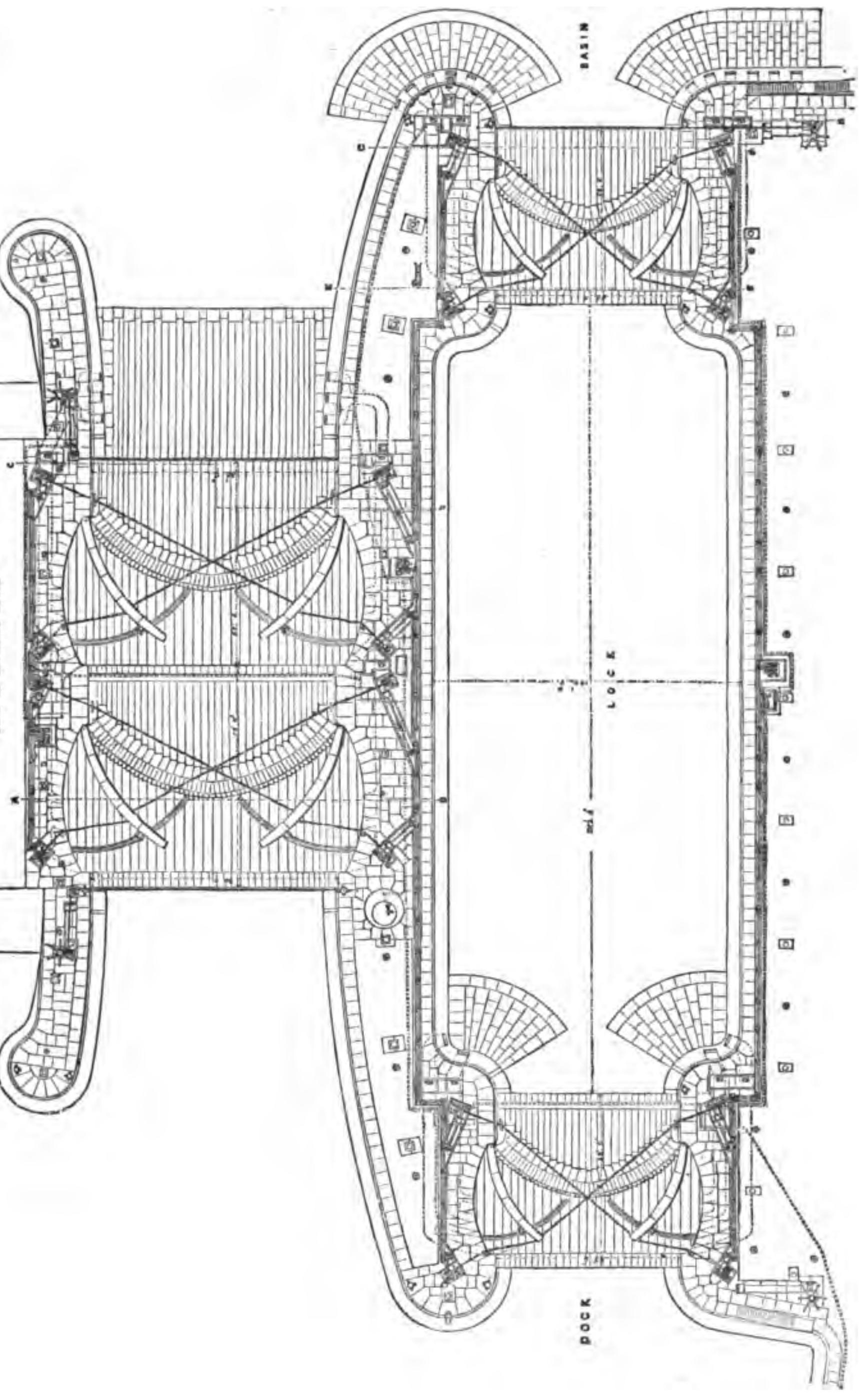


Shortly after the first course of masonry of the foundations was laid for the north or 60 ft. lock, Fig. 2486, the floor was observed to rise 3 in. very regularly, and forming a point. A bore-hole was put down, and on touching the stone head through 7 ft. of hard clay, a strong feeder of water came away. A pipe was put into the hole, and the water rose in it 13 ft. above the level of the foundation, rising and falling about 9 in. with the tide. The height to which the water rose was about the level of low water in the river, and it was clear no permanent injury could result when the works were completed. The bore-hole was, therefore, kept open, and similar holes were made in other places, and allowed to remain open during the progress of the works, being only closed up a short time before the water was let into the docks. The flooring of the lock went back partially after the hole had been opened some days. It was then heavily weighted with stone, and nearly restored to its original level. The masonry was built on the flooring originally laid, very few stones being taken out; and it has since shown no sign of settlement.

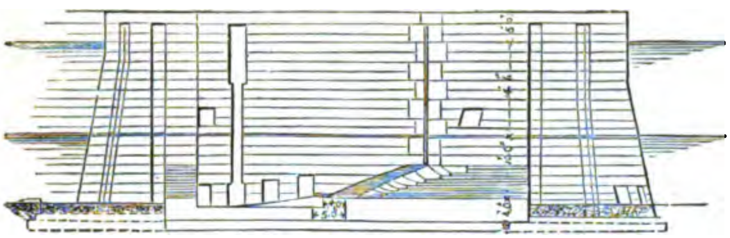
It was proposed to build a quay wall from P to O, Fig. 2484, opposite to the alkali manufactory. There being no clay at this part, it was intended to have built the wall on a strong foundation of piles, driven down to the stone head. But in forming the excavation to put in this foundation of piling, it was found that the slake would not bear the weight of the bank behind it, unless at a slope of 1 to 5. As so flat a slope was inadmissible, the plan adopted for overcoming the difficulty was by weighting the top with gravel, easily obtained from the old ballast hills at South Shields. The toe of the slope was thus forced out, and it was not an unusual thing to see the whole of the rails and wagons on the top gradually sink 10 or 12 ft. in a quarter of an hour; the toe of the slope at the same time rising and turning over rails and wagons in all directions. It was not until 150,000 tons of gravel had been deposited that the whole came to a state of rest. The slope is at present 1½ to 1. It is pitched with stone, and rests at the bottom on a strong row of piles. It can now be easily rendered available for quay purposes by the aid of timber when required.

2485.

PLAN OF ENTRANCE LOCKS.



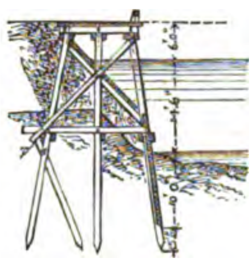
2486.



Longitudinal Section through centre of 60 ft. Lock.

2487.

2488.



Elevation and Cross-section of River Don Timber Wall, I K.

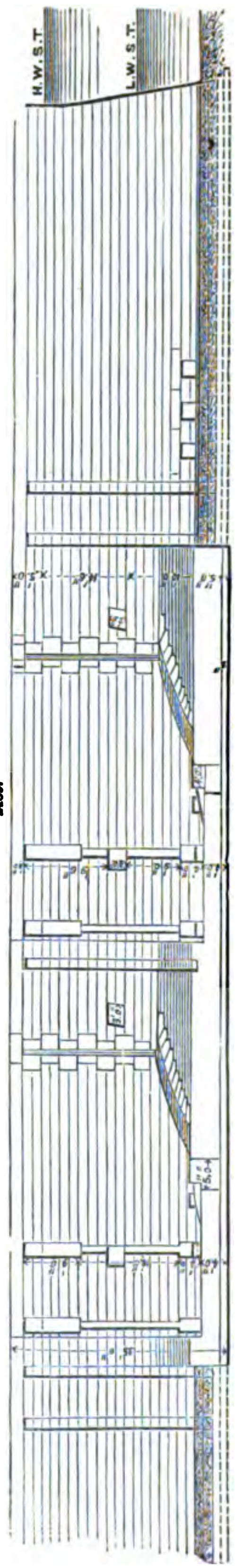
The extent to which the dock is walled is shown on the plan, Fig. 2484. The foundations of these walls rest in all cases on clay. The other sides or boundaries of the dock are of mud or slake with a slope of 1 in 5, partially pitched with stone. The mud or slake forms a good puddle, and can be worked very readily in dry weather. Fortunately the weather was remarkably fine during nearly the whole time of the execution of the works; had it been otherwise, the completion of the works would have been much delayed, and the contractor would have been put to additional cost, as a few days' continuance of wet weather sufficed to stop the work of excavation.

Several of the timber jetties for the shipment of coals are founded on this mud or slake. Experiments as to the bearing capacity of the slake were made by putting on the surface a bed of concrete 10 ft. square, and gradually loading it with iron. The result was, that with a load of 7 cwt. to the superficial foot no settlement took place; but as soon as that weight was exceeded the whole began to sink. The foundations of the jetties were, therefore, laid on a wide-spread base of concrete with timber sills, care being taken not to exceed a pressure of 5 cwt. to the superficial foot.

The position in which the entrance to the tidal basin is placed with reference to the course of the river, deserves attention. The river wall, which is constructed of creosoted timber, forms a curve of 2135 ft. radius. Plans, sections, and elevations of this wall are given in Figs. 2494 to 2498. Immediately below the entrance there was a bed of hard clay running out into the river. This has been entirely removed by dredging, and the flood and ebb tide now take their course as nearly as possible over the same channel, guided by the concave river wall, thus always ensuring a full depth of water opposite the entrance. In the case of the Northumberland Docks, which are on the opposite convex shore of the river, constant dredging is requisite to maintain the necessary depth of water at the entrance.

The dock gates, Figs. 2499 to 2509, may be noticed very briefly, as they are built on the model generally of those of the Victoria (London) Docks, which have been already described. The only point of difference is that the Tyne Dock gates are curved at the bottom, both on plan and in section, the pivot for the heel-post being raised 3 ft. 6 in. above the level of the sill, Fig. 2506. This mode of constructing the lock has its advantages, as by placing the pivot so high, there is less danger of anything lodging behind the heel-post. The construction of the invert of the lock is likewise very strong, as it is carried directly through from the end of the pointing sills. It has also its disadvantages, as it involves the necessity for some large and rather intricate masonry; but in this case there was every facility for executing any description of stonework. Some little trouble also arises in fitting accurately the doubly-curved wood sills to the doubly-curved masonry; but this was successfully accomplished, and the sills are perfectly tight. The alteration suggested by Kingsbury, in the mode of fixing the heel and mitre posts, is an improvement; as some little difficulty was experienced in making the gates water-tight at these points to ensure flotation. As soon as the gates were sufficiently advanced, they were

2489.

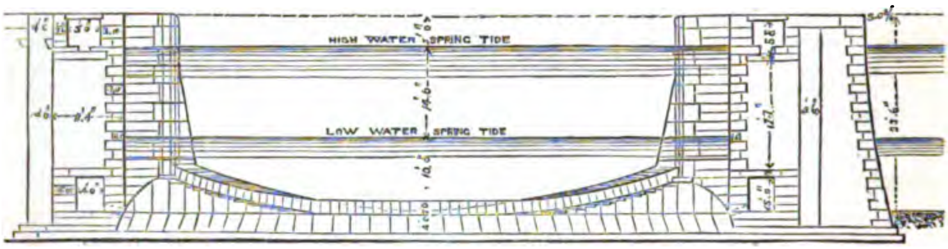


Longitudinal Section through centre of 80 ft. Lock.

their flotation, the weight on the rollers may be adjusted at pleasure. Instances are not wanting in gates with a large proportion of cast iron in them, where the rollers had to be renewed within a few years, owing to the great weight on the rollers, and the consequent rapid destruction of them. The expense of these renewals has often been very serious.

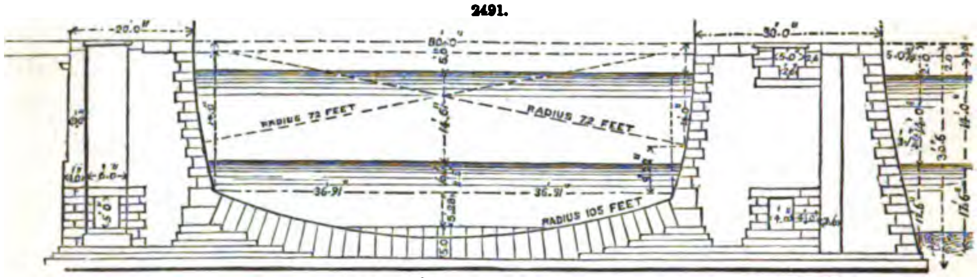
The sluices are all made to work with brass against brass. The sluices at Hartlepool were so constructed by Rennie, and on examination a short time ago they were found to be perfect. On the other hand, the sluices at the Monkwearmouth Dock, where brass worked on iron, were completely destroyed after being in use about eighteen years.

2490.



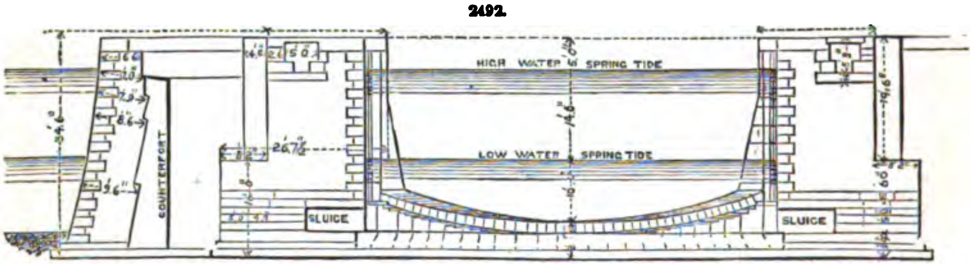
Cross-section A B

2491.



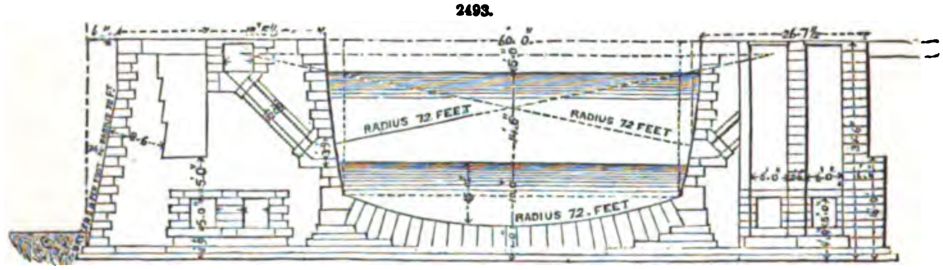
Cross-section C D.

2492.



Cross-section E F.

2493.



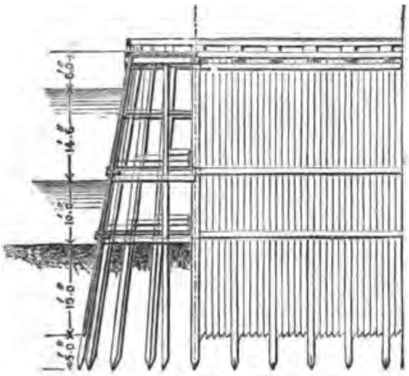
Cross-section G H.

The dock gates and sluices are arranged to be worked either by hand or by hydraulic power. Where hydraulic power is used for dock gates or for sluices, it is essential to have the power of working by hand when required; and circumstances have already arisen showing the necessity for the occasional use of hand-power.

As a large quantity of muriatic acid was constantly discharged from the alkali-works during

the construction of the docks, the tidal water was allowed to flow in a canal as far up the face of the alkali-works as the point where the acid was discharged. In order to provide for the permanent discharge of this acid, a large tank capable of holding 10,000 gallons of water, formed of creosoted timber, has been constructed at the end of the discharge pipes from the works. From

2495.



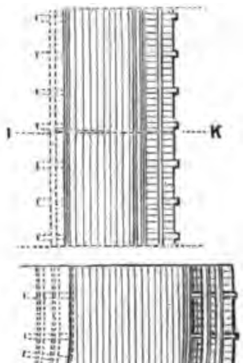
Section and Elevation of Pier End.

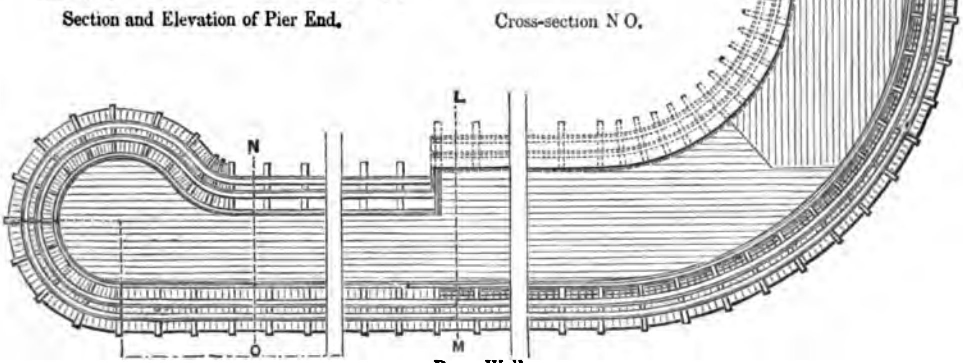
2496.

Cross-section N O.

2494.

River Don Timber Wall.

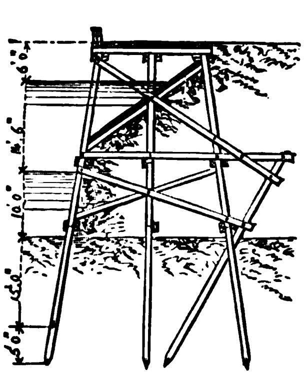




River Wall.

this tank, fireclay pipes boiled in creosote are laid to the edge of the quay of the dock basin, and from thence to the point of discharge, 2 ft. below the level of low water in the bed of the river, square boxes of carefully-creosoted timber are laid. Many experiments were made during the progress of the works to ascertain what would best resist the destructive action of the muriatic acid, and nothing was found to be more successful than the plan adopted. The acid being now discharged on the ebb tide, is carried away in so diluted a state as not to produce any injurious effects.

2497.



Cross-section L M.

2498.

Elevation of River Wall.

A branch line of railway is laid down to the level of the dock quay, and all round the docks, in order to afford facilities for any description of traffic.

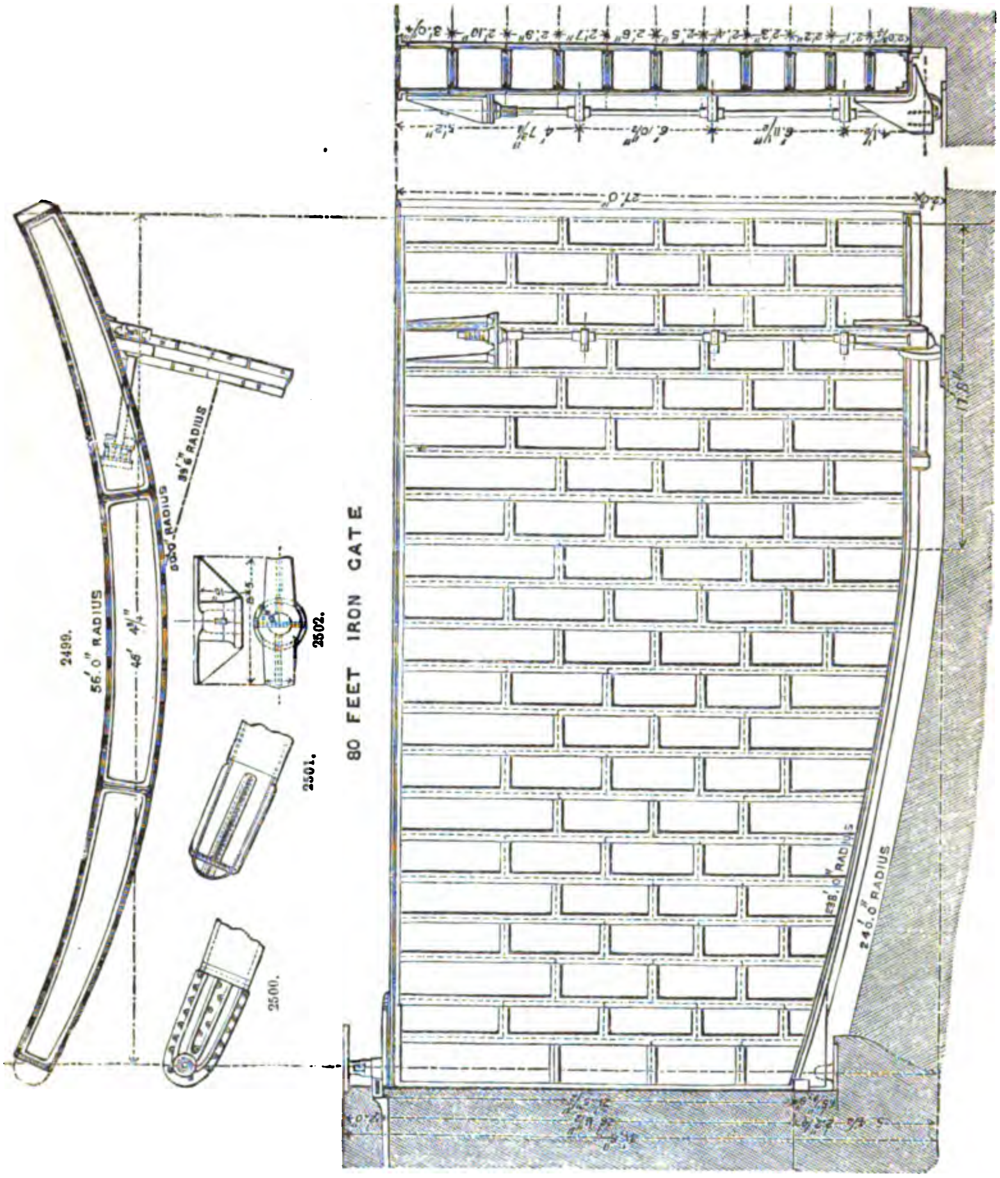
The primary object of the construction of the Tyne Docks was to provide accommodation for the shipment of the large quantity of coals brought to South Shields from the coal-fields of Durham and Northumberland.

The coal trade of the northern coal-fields has been gradually increasing for many years past. The quantity of coals shipped in the river Tyne in the year 1858 amounted to 4,181,000 tons; of this amount, 1,203,524 tons, or nearly 29 per cent., were shipped by the North-Eastern Railway Company at South Shields. The total quantity of coals shipped at all the north-eastern ports in the year 1858, between the Blyth and the Tees, was 9,899,600 tons; of this amount, 3,005,785 tons, or rather more than 30 per cent., were shipped at Shields, Sunderland, and Hartlepool, by the North-Eastern Railway Company. The facilities for shipping at South Shields at the command of the North-Eastern Railway Company, have for some time been so limited, that it has been necessary to work

night and day throughout the whole year; and even then the requirements of the trade could not be satisfied.

As the method of shipping coals has undergone many changes during the last forty-seven years, it may not be uninteresting to give a brief account of the various modifications which have been made.

For many years on the Wear, and in those cases on the Tyne in which the vessels could not be loaded direct from the colliery railway, the coals were brought down to the edge of the river in wagons, and there put into keels, which were broad, flat-bottomed barges, each containing a keel of coals, or 8 Newcastle chaldrons, or 21 tons 4 cwt.



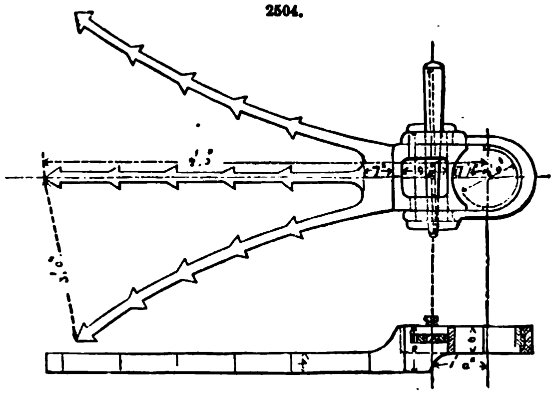
2499. 2500. 2501. 2502. 2503.

On the river Tyne there were many collieries having communication by railways to shipping places where vessels could load, as in the case of the Walls-End Colliery. The mode of shipment was by spouts, in their general principles similar to those adopted at the Tyne Docks; but without, for a long time, any arrangement for meeting the difference in the level of the tide and in the size of the vessel. When keels were used, the coals were brought down in them to where the vessel lay in the river; and they were then cast into the vessel, through the port-hole, by the keelmen. This system still exists, to a limited extent on both rivers, in the case of those collieries not having the

means of direct railway communication to a place of shipment. When in full operation, before the general introduction of railways, this system gave employment to a remarkably fine body of men known as keelmen.

The first innovation on the spout system took place in the year 1812, when a coal-drop was erected at Pelaw Main Spout, on the river Tyne, by Benjamin Thompson, and further improved by him in 1813. The principle of this mode of shipping coals had been previously patented by William Chapman, of Newcastle. The drops, as erected by him in 1813, have been generally followed, with various modifications. The principle of all these drops is, that the loaded wagon in its descent raises a counterbalance weight, and when the coals are let out of the wagon, the counterbalance weight brings the wagon back to its previous position, the whole being under the control of powerful brakes.

2504.



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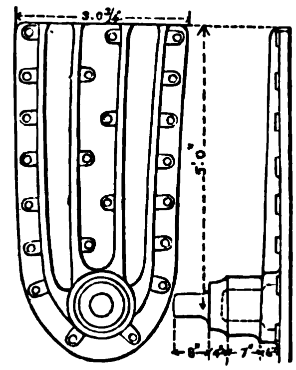

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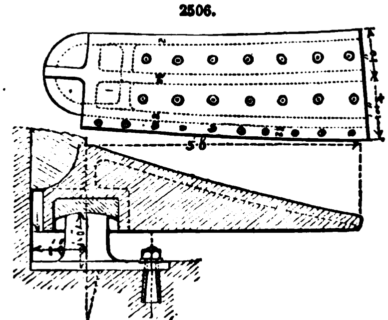

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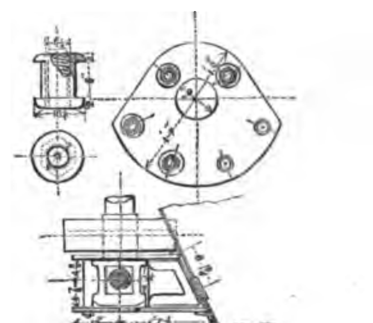

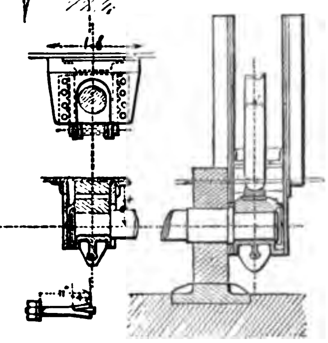

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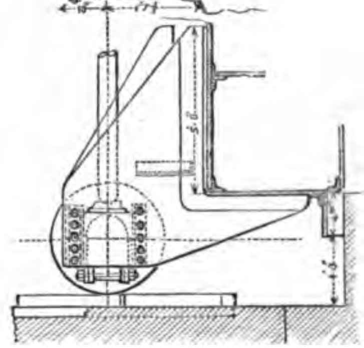


2508.

The first change on the keel system took place on the river Wear in the year 1817, when, in order to avoid the breakage to which the coals were subject by transhipment first to the keel and then from the keel to the ship, a system of tubs fitted into the keels was invented by William Bell. The chaldron wagons were lowered immediately over the keel, and then dropped into the tubs. The tubs were then conveyed in the keels to Sunderland, and transferred by the machinery to the vessel. This system of machinery was invented and constructed by Burlinson, of Sunderland, in the year 1817, who also, in 1825, erected the machinery which is still at work at Sunderland.

William Chapman also invented a floating barge, which was fitted with a steam-engine and

machinery, by which the tubs were transferred from the keel to the ship. This was used for some time, but it was found to be very unwieldy, and was therefore superseded by the fixed machinery on land.

In determining the system to be adopted in the Tyne Docks, the question lay between drops, by which the wagon would be lowered directly on to the deck of the vessel, and a system of spouts, with more perfect appliances for preventing the breakage of the coals. After mature deliberation, watching carefully the best-constructed spouts, and considering not only what existed but what might be done, it was decided to adopt the system of shipping by spouts.

The variation in the level of the deck of a large American ship when light, and at high water of a spring tide, and in the level of the deck of a small vessel loaded at a neap tide, is 20 ft., and it was necessary to provide for this difference. See Keels and Coal Shipping.

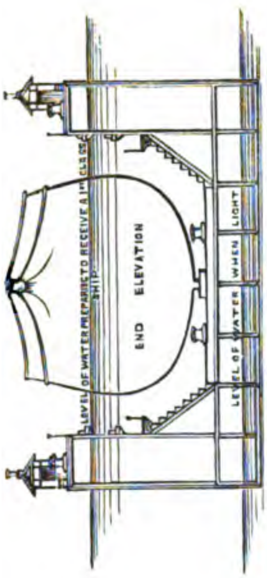
Figs. 2510 to 2513 illustrate *G. B. Rennie's Iron Floating Dock*, constructed for the port of Ferrol on the Atlantic. Such docks serve the same purpose as the ordinary graving docks.

The total length of this dock, Fig. 2510, is 350 ft.; the breadth of the base 105; the height from the floor to the deck of the side walls 37 ft. 6 in. Thus, allowing 5 ft. for the keel-blocks, and 2 ft. 6 in. between the top and the highest water-level, there remains 30 ft. depth of water for the admission of ships. The total displacement of water by the base is 13,000 tons, the weight of the whole dock about 5000, thus leaving a surplus of 8000 tons for lift. The dock is constructed in the following manner;—The section shown in Fig. 2510 is that of the whole length of a dock, and is composed of plate, angle, and T iron, riveted together so as to form one structure. The base or pontoon of the above is 12 ft. 6 in. deep, divided into two compartments by a water-tight bulk-head running the whole length of the dock. Each of these is subdivided into smaller compartments by ten transverse bulk-heads, forming eleven water-tight chambers on each side, Figs. 2511, 2512. The side walls are also divided by a similar number of transverse bulk-heads. The upper part of the side walls is composed of air-tight chambers of a capacity rather exceeding a volume of water whose weight is equivalent to that of the dock. These serve the purpose of preventing the dock sinking below a certain level. The base is again divided and strengthened by open lattice girders of an I form, of a length equal to the breadth, and depth equal to the depth of the base or pontoon. They are about 5 ft. apart. On commencing the work, two of these girders were tested with a weight of 200 tons without any perceptible deflection. The base is further strengthened longitudinally by a system of diagonal bracing. There are thus, including the outside plating, nine elements of strength in a longitudinal direction in order to distribute any inequality of weight that may occur through irregularity in the keel or weight of the ship. The floor of the dock, Fig. 2513, is covered with 3-in. teak planking, upon which, supported by every third girder, is a solid teak beam of 2 ft. square running from side to side. These beams support the keel-blocks and movable bilge blocking-pieces, with rack and pawl. On the middle of the intermediate girders the ordinary keel-blocks are fixed.

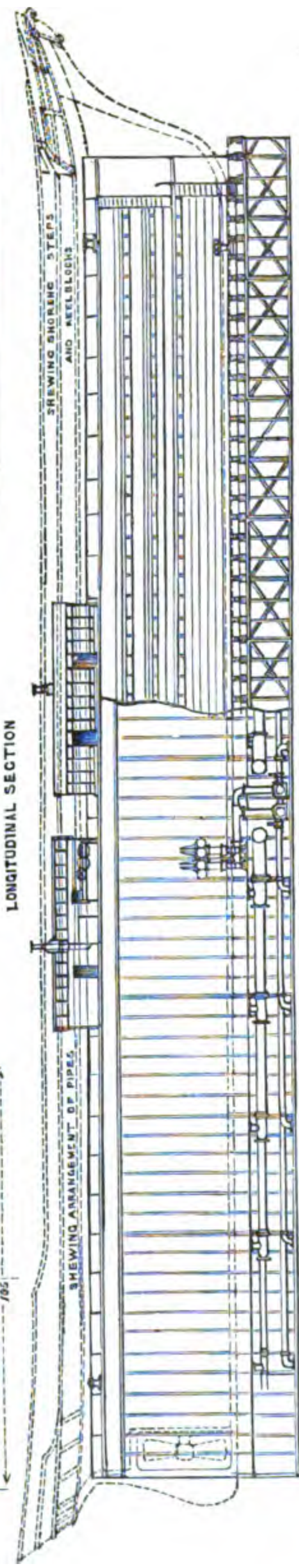
The Arrangement for Sinking, Filling, and Pumping out.—On either side of the dock, near the centre at the bottom, are two large sluices. These admit the water into a small reservoir or distributing chamber, from which wrought-iron pipes 1 ft. 6 in. diameter lead, one to each compartment. These pipes have sluices or cocks fitted to them, which are worked by hand from the top of the dock, so as to be always available and capable of regulation by the man in charge. The depth of water in each compartment is determined by an ordinary gauge. Four pumps are placed on each side, having 2 ft. 9 in. stroke, and 26 in. in diameter, and worked by a pair of high-pressure steam-engines, with cylinders of 18 in. diameter and 2 ft. stroke of piston. The pumps are reduced in speed in the proportion of 2 : 1 by means of gearing. Four powerful capstans and mooring bollards are fixed at each end of the dock for moving or mooring it *ad libitum*.

The dock is worked as follows;—Suppose it empty, and the floor well above the level of the water, the sluices at the side are gradually opened, and water allowed to flow into the different compartments. The dock will then commence sinking, care being taken by watching the gauges so to regulate the supply of water that it may sink uniformly and gradually. When the dock is sufficiently deep to take in the required vessel the sluices are closed, the vessel hauled over the keel-blocks, and the breast and other shores applied, while the engines are set to work to pump the water out. Thus for every ton of water pumped out 1 ton of dock and ship is lifted. This operation is continued until the floor of the dock is well out of the water, as shown in Fig. 2511. Painting, examination, or repairs, can then be performed with facility. The manifest advantages of this arrangement are;—First, the adaptation of breast shores, which those accustomed to docking large vessels well know the importance of, for steadying ships when they begin to rest on the keel-blocks. Secondly, the longitudinal stiffness obtained by the side walls, so that any undue pressure arising from irregularity in the keel of the vessel is thereby counteracted, the height of keel-blocks being regulated as usual by wedging up. Thirdly, the facility of moving the dock should it be required. Fourthly, the simplicity of the action of the dock, and its non-liability of getting out of order. Fifthly, entire independence of the rise and fall of the tide, and thus readiness for docking or undocking at any moment. Suppose, for instance, either from action in battle, or derangement of the sea-cocks, or of a hawser round the screw, ships run into Spithead, Portland, or Plymouth, to be docked, and have to wait for the tides as usual, serious inconvenience might result; whereas if a floating dock were fixed at any of the above-named or other ports, they would run in, and not be required to discharge stores or cargo, and in two or three hours be in a position for examination; and from the now universal introduction of steam for ships, these slight derangements, which can be often remedied in an hour or so, not unfrequently occur. Should, however, it be found that a repair of some weeks or so would be required for the vessel, the dock being thus in use would not be available as above described. To remedy this, Rennie contrived a floating basin and a railway for Carthagena. It is designed for the especial purpose of hauling the dock with the vessel upon it into the basin, and conveying the vessel from the dock on to a horizontal slip or way, and thus leaving the dock available for other vessels.

2512.



2510.



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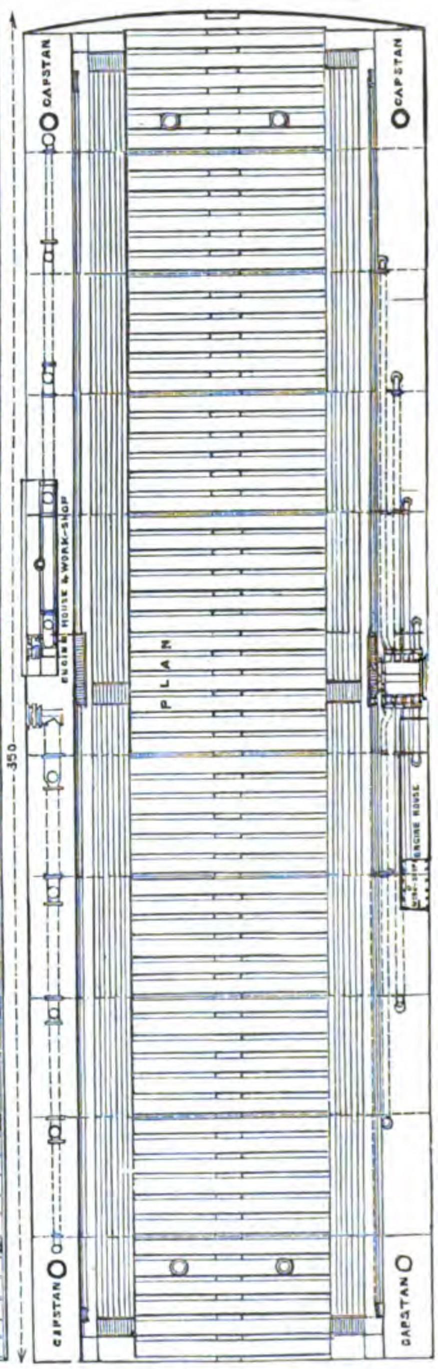
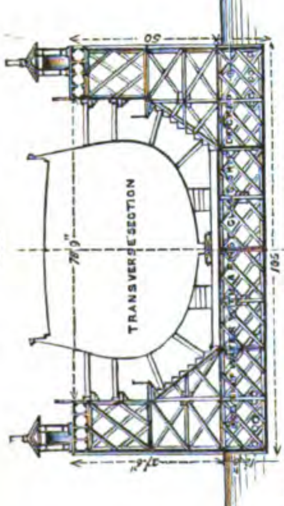


2511.



An iron floating dock for Bermuda has been recently constructed by Campbell, Johnstone, and Co., of North Woolwich. This dock is capable of docking ships of the Bellerophon class when waterlogged; it is fitted with a caisson at each end, and has a double bottom and sides 20 ft. apart. The principal dimensions are as follows;—

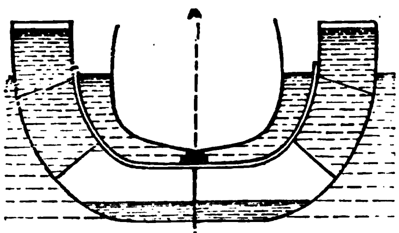
	Feet.
Length over all	381
Length between caissons	330
Breadth over all	124
Breadth inside of dock	84
Depth over all	72

It is divided longitudinally into eight water-tight compartments on each side of the keel, and each of these is again divided into three smaller compartments, not water-tight. Transversely it is divided into three compartments on each side of the keel, called, respectively, the load-chamber, balance-chamber, and air-chamber; these chambers being water-tight and distinct from each other, Fig. 2514.

The dock, when not in use, has its chambers empty, with the exception of the air-chambers, in which a quantity of water is always kept for supplying the pumps to fill the load-chambers when required.

The process of docking a vessel may be described thus;—The load-chambers are first filled by pumping engines fitted on the top of the dock, and having suction-pipes leading into the air-

2514.



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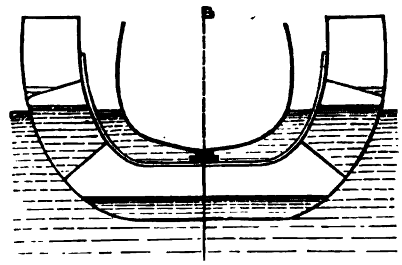

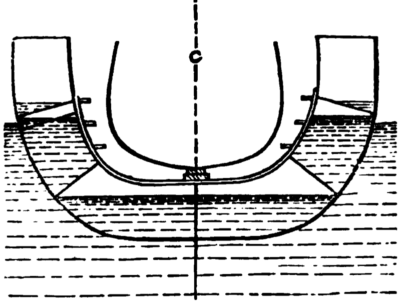

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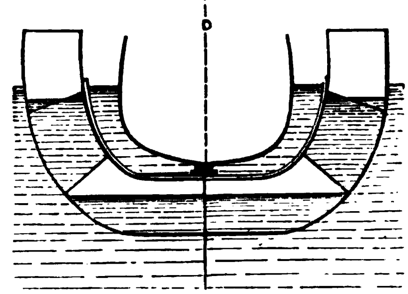
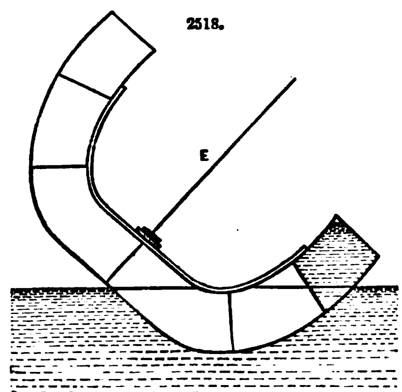


2517.

2518.



chambers. After this has been done, the valves fitted at the lower part of the balance-chamber and communicating with the sea are opened, and the chambers filled, this operation sinking the dock to such a depth that, by opening valves fitted through the caissons, water can be run into the dock in order to bring the contained water to the same level as the water on the outside, when the caissons can be taken out, and there will be a depth of 27 ft. of water on the blocks, Fig. 2514.

The ship having been brought over the blocks, the water in the load-chambers is allowed to run out, and the balance-chambers partly emptied, if required, Fig. 2515; the ship is now breast-shored, and the caissons put in place, after which the water remaining in the dock is run into the air-chambers, as shown at Fig. 2516, by means of valves fitted in the bottom of the dock, in which state the dock remains until the vessel is ready for undocking. Should the vessel not be exactly in the centre of the blocks, the dock is brought perpendicular by letting a portion of the water out of the balance-chamber on one side or the other, as the case may require.

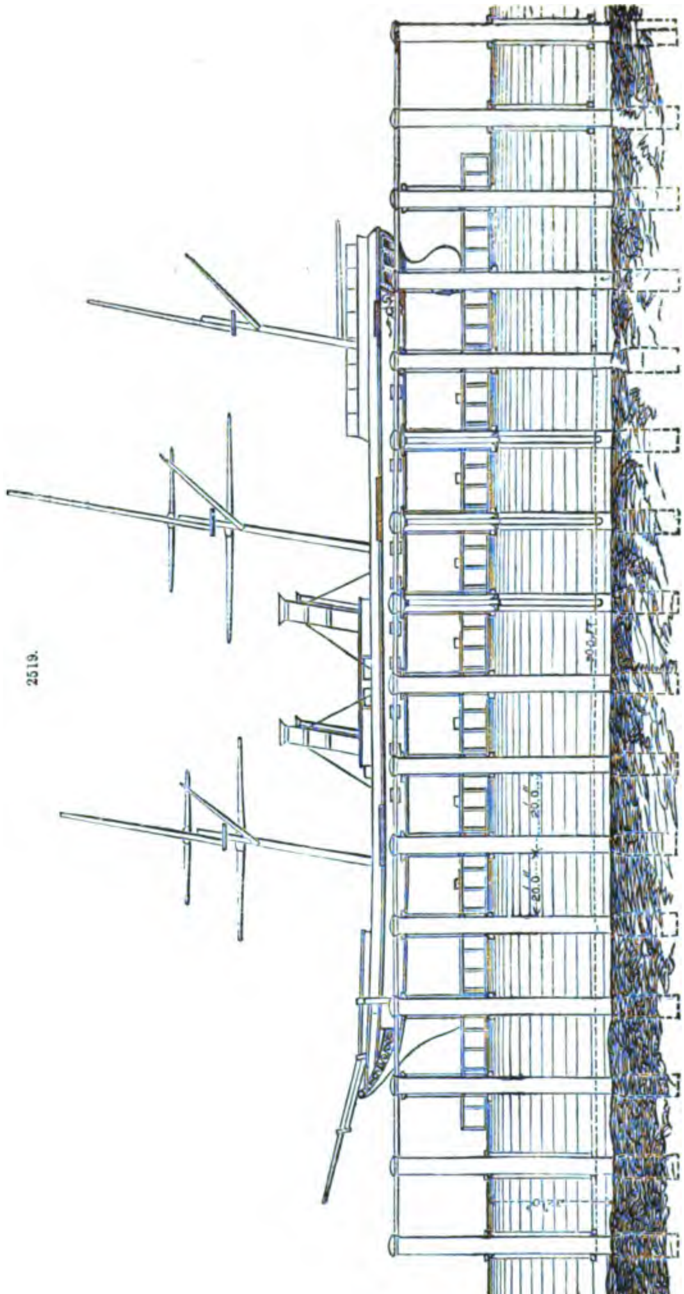
To undock the vessel, water is run into the dock through the valves in the caissons, and the balance-chambers filled up, this bringing the dock into the position shown in Fig. 2517, with the ship afloat; the caissons are then taken out, when the vessel may be undocked. To bring the dock again ready for use the water in the air-chambers is pumped into the load-chambers and run into the sea, in order to allow the dock to be emptied into the air-chamber. Fig. 2518 shows the dock heeled over, in order to clear or repair the bottom.

In docking small vessels the dock has sufficient buoyancy to lift them quite out of the water, when the caissons would not be required. The inventor also proposes to make pontoons capable of carrying light vessels to fit the inside of the dock; these pontoons he sinks in the dock, and after bringing the vessel over it, the dock is raised and the water let out of the pontoon, when the dock is again sunk, leaving the pontoon afloat with the vessel on it; by these means a number of ships, corresponding to that of the pontoons provided, might be repaired at the same time.

Edwin Clark's Hydraulic-lift Dock, Figs. 2519 to 2523.—Clark, under the direction of Robert Stephenson, designed the machinery, and superintended the raising of the tubes of the Britannia and Conway tubular bridges; and it required but trifling ingenuity to apply the process employed to raise those tubes to the lifting and docking of vessels.

The site selected for one of those hydraulic-lift docks was a plot of 26 acres of level land, lying between the Victoria Docks and the Thames, and below the level of high water. This site admitted of a direct entrance from the docks, with a permanent water-level, without the cost and delay of a special entrance from the river. The soil is a deep bed of bog and alluvial mud, on a substratum of gravel. The only excavation necessary was the lift pit, and its deep entrance to the dock, where a coffer-dam was employed.

2519.



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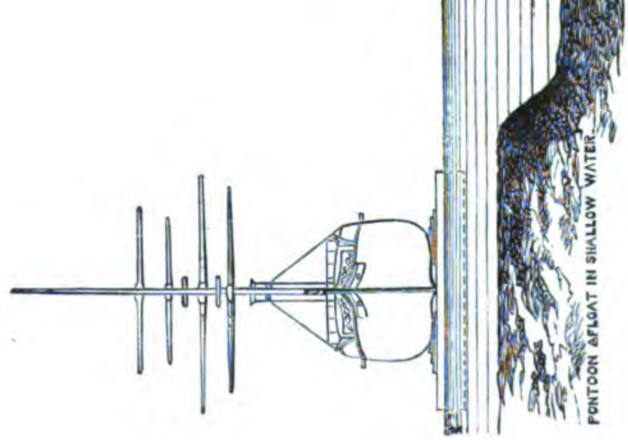

The depth of water in the lift is 27 ft.; over the remaining water space it is only 6 ft., which is the maximum draught of the pontoons. In this shallow-water space there are eight pontoon berths, separated by jetties for workshops and access; each berth being 60 ft. wide, and from 300 ft. to 400 ft. long, and surrounded by brick retaining walls. The bottom was covered with a level layer of peat clay, to prevent leakage to the gravel beneath. A sluice through the surrounding bank renders it easy, at low water, to empty the whole of the space; but when this is done, a dam must necessarily be thrown across the upper end of the lift, to cut off access to the Victoria Docks. The area of shallow water is 16 acres, affording sufficient space for floating fifteen or twenty pontoons, which, it was estimated, was about the number that might be kept employed by a single lift.

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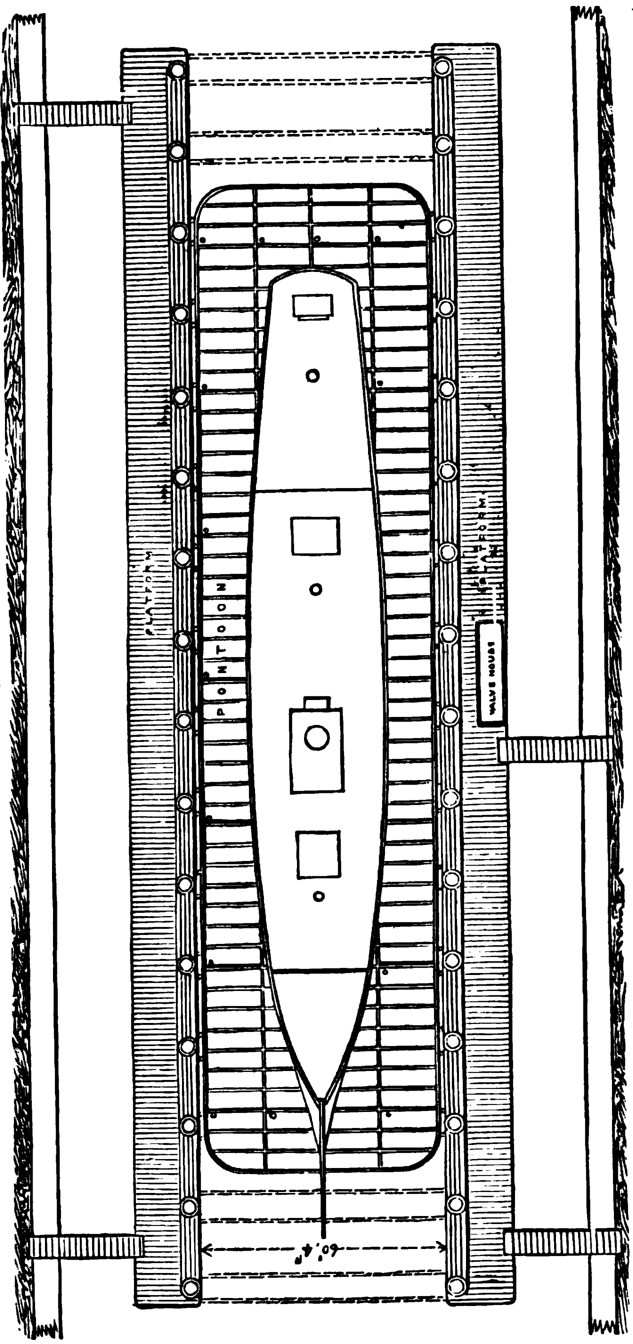


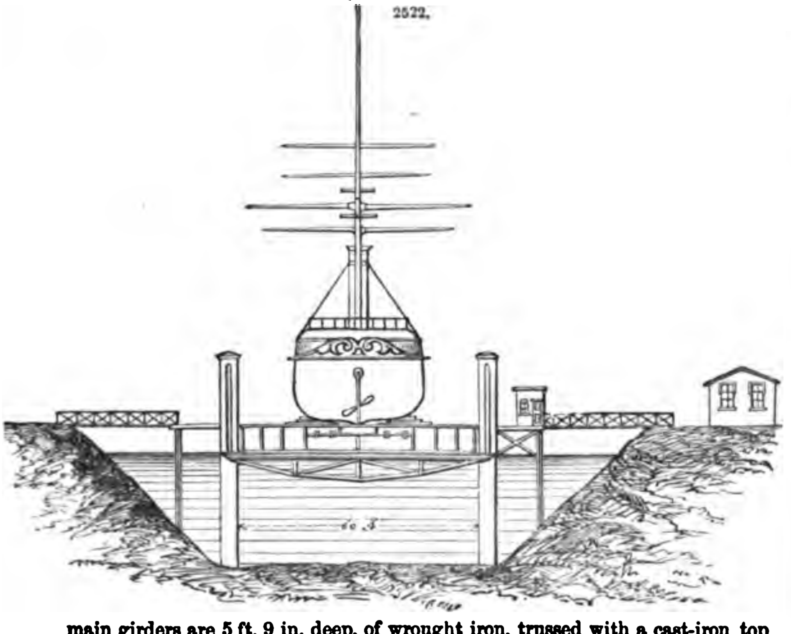
The docking of a vessel consists of two distinct operations. First, the direct raising of the weight on the lift; second, the transportation of the vessel to any convenient position for its repair on the pontoon.

The lift is a direct mechanical appliance for raising the vessel by means of hydraulic presses. It consists of two rows of cast-iron columns, each 5 ft. in diameter at the base, and 4 ft. in diameter above the ground-level, and sunk about 12 ft. in the ground. The clear space between the two rows is 60 ft., and the columns are 20 ft. apart from centre to centre, and are placed on each side of the excavated lift pit, in about 27 ft. of water. There are sixteen columns in each row, giving a length of 310 ft. to the lift; but, as vessels may overhang at each end, there is a practical working length of 350 ft. The columns were sunk in the usual manner, three or four being thus fixed each week. When the requisite depth was attained, the base was filled with concrete, and covered with a layer of 2-inch planks, to act as a cushion for the cast-iron seat on which the press rests. No great accuracy of position is required, as the suspended load tends to bring all the columns vertical, and if any column should, during use, be even sensibly thrust deeper into the soil, the ram follows its work, independent of the level of the press. The columns, Fig. 2523, support no weight, but act solely as guides for the cross-heads of the presses, which move in slots reaching from the top of the presses (just clear of high water) to the top of the columns. The column is covered by a cap, Fig. 2519, and each row is firmly connected together at the top by a wrought-iron framed platform, running from end to end of the dock on each side.

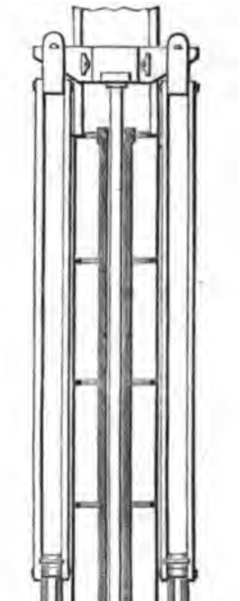
This platform forms a convenient permanent scaffold for raising the rams. The whole length of a column is 68 ft. 6 in. A scale is printed on each column to register the motion of the cross-heads while rising or falling.

The presses and girders are managed as follows;—Each column encloses a hydraulic press of 10 in. diameter, with a length of stroke of 25 ft.; the top of the press is just clear of the highest water, and it is kept in place by a collar or diaphragm in the column. The rams are solid, and each carries a boiler-plate cross-head 7 ft. 6 in. long, thus extending 1 ft. 9 in. beyond the column on each side. From the ends of the cross-head are suspended, by wrought-iron bars, two iron girders, each 65 ft. long, which extend entirely across the lift to the corresponding column and press on the opposite side. There are thus sixteen pairs of suspended girders, lying at the bottom in 27 ft. of water, when the presses are lowered, but rising above the surface when the presses are raised. They form a large wrought-iron platform, or gridiron, which can be raised or lowered at pleasure, with a vessel upon it. The detail of the machinery is identical with that employed at the Conway Tubular Bridge; and those who saw that bridge raised have only to imagine thirty-two tubes side by side instead of two, and they will have a perfect representation of the lift. The

2522.



2523.



main girders are 5 ft. 9 in. deep, of wrought iron, trussed with a cast-iron top flange. The sectional area of each ram being 100 circular inches, a pressure of 2 tons to the circular inch gives 200 tons as the lifting power of each press, or 6400 tons for the whole lift; but to find the available lifting power, there must be deducted 620 tons, which is the weight of the rams, cross-head, chains, and girders, leaving 5780 tons for the pontoon and vessel. The presses were tested at 2½ tons to the circular inch. The girders are designed for carrying the vessel as a load at the centre, although the load is distributed by the pontoon, and the wide base used for the blocks. The water is forced into the presses immediately beneath the collars at the top, this being an accessible position.

The grouping of the presses was an important consideration. If each press were worked entirely independent of its neighbours, it is evident that precisely the same quantity of water must be thrown into each press to avoid unequal strain. Again, if the whole number were supplied from a common head, the slightest excess of weight at any part of the platform or gridiron would lower that part, the water passing back through the pipes to the presses where less pressure existed; the same difficulty would be experienced with two groups, however arranged. Stability is, however, secured by arranging the presses in three groups. One-half of the whole number, occupying the upper half of the lift, form one group, consisting of sixteen presses. The remaining eight presses on one side form a second group, and the opposite eight form the third group.

The presses in each group are all connected, so that perfect uniformity of pressure is secured in each as regards the individual presses, while the three groups are so arranged that their centres of action form a tripod support, upon which the pontoon is seated. As any one point of the tripod may be raised or lowered without regard to the other two, by the most simple manipulation, the pontoon can be either maintained perfectly level, or any inclination can be given to it that may be desired.

Any pair of presses may be instantly cut off in the valve-room by means of a plug, during the operation of lifting, without interrupting the process. One or more of the end pairs is almost invariably out of use, except with vessels of the largest class. No delay, therefore, arises from the failure of a collar or pipe, and even should a press burst, the water can only escape slowly through

the ½-in. pipe which feeds it; and by opening the escape-valves in the other groups, vessels, partially raised, descend slowly and steadily into the water.

The force-pumps are 1¼ in in diameter. There are twelve pumps, worked by direct action by a 50-horse-power engine; six of these pumps are used for the large group, and three pumps for each of the smaller groups. The power when required is increased by cutting off one or more of the pumps. The engine-house is, unfortunately, 112 yds. from the lift, the water having to be driven all this distance through pipes only ½ in. in diameter. On account of the distance of the engine, a valve-house, for the manipulation of the presses, is erected on the platform alongside the lift. During an operation the engine continues to pump, and the valve-man throws the water into either group, or to waste, at pleasure. The raising of a vessel occupies about twenty-five minutes. The pipes and presses are, to a considerable extent, sheltered from frost by their position, and during the severest cold a few occasional strokes of the engine are found sufficient to keep all in motion, and prevent congelation.

The pontoons are not essential for raising or docking a single vessel, for it is evident that the lift, as described, is all that is required for that purpose. The girders might be connected together by other longitudinal girders, so as to form a sufficiently rigid platform; or the whole might be formed into a pontoon, which would support a vessel after it was raised.

The following is the arrangement adopted;—An open pontoon, proportioned to the size of the vessel to be docked, is selected. Keel-blocks and sliding bilge-blocks, adapted to her shape, form part of the pontoon, which is placed on the girders, and sunk with them to the bottom of the dock. The vessel is brought between the columns, and moored securely over the centre of the pontoon. By lifting the girders the keel-blocks are first brought to bear under the keel of the vessel; the side blocks are then hauled in, by chains laid for the purpose on each side the dock, and the gridiron and the pontoon, with the vessel upon it, are then all raised by the presses clear of the water. The pontoon is provided with valves in the bottom, and thus empties itself of water. The valves are closed, and the girders again lowered to the bottom, but the pontoon, with the vessel upon it, remains afloat. Thus, in about thirty minutes, a vessel drawing 18 ft. of water is left afloat on a shallow pontoon drawing only 4 ft. or 6 ft., and may be taken into the shallow dock prepared for its reception. These docks are surrounded by workshops and tools, with shelter for the men close up to the bulwarks of the ship. The vessel is, in fact, brought bodily into the centre of a convenient workshop. It is taken to the smiths', or the carpenters', or the machine shops, according to the nature of the repairs required, and is moved easily from one to the other.

The number of vessels that can be thus docked is limited only by the number of pontoons, each pontoon constituting a separate and independent dock. The pontoons, which are all about 58 ft. wide, vary in length and depth according to the class of vessel intended to be docked, and are rectangular in form, and open decked. The sides are vertical, and are strengthened longitudinally and transversely by wrought-iron girders, running from side to side, and from end to end, and thus forming a series of rectangular divisions. The pontoons are divided into water-tight compartments by means of bulk-heads formed of the girders, each compartment being provided with a circular valve in the bottom, closed by a screw-shaft. The transverse girders are 8 ft. apart, and support the bilge-blocks on their upper flanges. In the largest pontoons these girders form inclined planes, declining in height towards the centre, to facilitate the running in of the block-frames. There is a strong longitudinal centre girder, with a broad top flange, for supporting the keel-blocks; on each side, the two other longitudinal girders are placed equally distant, and in the line of the side blocks.

TABLE I.—DIMENSIONS OF DRY OR GRAVING DOCKS.

Name or Number of Dock.	Length in Blocks at Bottom of Dock.		Length at Top of Dock.		Width of Entrance.		Depth of Water on Sill at O. W. H. Spring Tides.		Depth of Water at O. H. M. Neap Tides.		Remarks.
PORTSMOUTH.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
No. 1, South harbour dock	228	3	253	6	57	7	20	3	16	3	Number of building slips—one of 1st class and four of 2nd class.
„ 2, South-east basin dock	221	6	252	10	63	4	24	0	20	0	
„ 3, South basin dock ..	275	2	287	1	67	6	25	6	21	6	
„ 4, Middle basin dock ..	279	3	286	3	67	6	21	9	17	9	
„ 5, Middle basin dock ..	208	3	227	2	55	4	20	3	16	3	Being made 4 ft. 3 in. deeper.
„ 6, Harbour dock	189	8	220	1	52	11	20	0	16	0	
„ 7, „ 10, Double docks	644	10	644	10	80	5	25	6	21	6	
					88	6	27	0	23	0	
„ 8, South inlet dock ..	302	10	333	5	70	0	22	9	18	9	
„ 9, Dock	253	4	283	2	64	11	21	9	17	9	
„ 11, North inlet dock ..	406	0	426	0	70	0	25	9	21	9	In course of construction.
DEVONPORT.											
No. 1, Basin dock	266	0	299	0	65	0	27	10	23	4	
„ 2, „ 3, ...	415	6	437	0	73	0	31	1	27	7	Two old docks being altered one. New one (constructing).
„ 4, ...	209	6	241	2	56	2	20	4	15	10	
„ 5, ...	263	4	275	10	64	0	20	7	16	1	Number of building slips—one of 1st class, two of 2nd class, and three of 3rd class.

Table I.—Dimensions of Dry or Graving Docks—*continued.*

Name or Number of Dock.	Length in Blocks at Bottom of Dock.		Length at Top of Dock.		Width of Entrance.		Depth of Water on Sill at O. W. H. Spring Tides.		Depth of Water at O. H. M. Neap Tides.		Remarks.
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
Keyham.											
No. 1, South dock	348	2	356	6	80	0	23	0	20	0	
„ 2, Middle dock	281	9	308	0	80	0	23	0	20	0	
„ 3, Graving dock	274	6	307	0	80	0	27	0	24	0	Being altered and made 136 ft. 6 in. longer on keel-blocks, and 109 ft. at tops.
Sheerness.											
No. 1, Dock	241	0	253	4	57	7	25	2	20	8	
„ 2, „	225	7	251	10	57	8	25	2	20	8	
„ 3, „	241	0	253	4	63	5	25	2	20	8	Number of building slips—one of 2nd class.
„ 4, „	180	7	203	10	50	3	19	10	15	4	
„ 5, „	154	4	196	1	58	7	14	8	10	2	
Chatham.											
No. 1, Dock	203	5	222	5	57	0	16	0	13	0	
„ 2, „	374	6	397	9	62	2	23	6	20	6	Number of building slips—one of 1st class and six of 2nd class.
„ 3, „	320	5	347	5	62	10	23	6	20	6	
„ 4, „	232	0	253	0	62	8	21	0	18	0	
Woolwich and Deptford.											Number of building slips—one of 1st class, seven of 2nd class, and four of 3rd class.
No. 1, Dock	250	0	265	0	65	0	22	0	17	2	
„ 2, „	241	3	272	0	65	0	21	0	16	2	
„ 3, „	264	0	290	8	80	0	21	0	16	2	Being made 10 ft. longer on the blocks, and 74 at the top
Outer dock, Deptford	196	0	196	0	54	0	15	8½	9	8½	
Inner dock, Deptford	167	6½	190	4½	46	10	13	3	7	8	
Pembroke.											
No. 1	387	8	404	0	75	0	24	6	18	6	Number of building slips—four of 1st class and nine of 2nd class.
Cherbourg.											
No. 1, in outer basin	..		246	0	58	0	..		..		
„ 1, in new basin	..		370	0	60	0	..		..		
„ 2, „	..		370	0	60	0	..		..		
„ 3, „	..		340	0	60	0	..		..		Number of building slips—nine of 1st class.
„ 4, „ ..	..		340	0	60	0	..		..		
„ 5, „	..		340	0	60	0	..		..		
„ 6, „ double locks	..		350	0	65	0	..		..		
„ 7, „ „	..		350	0	65	0	..		..		
Brest.											
No. 1, small	..		210	0	56	0	..		..		
„ 2, „	..		210	0	56	0	..		..		
„ 1, double	..		500	0	60	0	..		..		Can be made into four of 250 ft.
„ 2, „	..		500	0	60	0	..		..		
L'Orient.											
No. 1, double	..		340	0	58	0	..		..		Recently lengthened.
„ 2, „	..		600	0	..		..		..		Constructing.
Toulon.											
No. 1, old	..		250	0	58	0	..		..		
„ 2, „ smaller	..		230	0	58	0	..		..		
„ 3, „ „	..		230	0	58	0	..		..		
„ 1, new	..		336·69		62	0	..		..		Number of building slips—sixteen of 1st class.
„ 2, „	..		396·88		..		..		..		
„ 3, „	..		545·79		..		..		..		
Rochefort.											
Small	..		210	0	55	0	..		..		
Double	..		450	0	60	0	..		..		Can be made into one of 210 and one 240.
Large	..		360	0	80	0	..		..		
Havre.											
New dock	..		426	0	90	0	..		..		

TABLE I.—DIMENSIONS OF DRY OR GRAVING DOCKS—*continued.*

Name or Number of Dock.	Length in Blocks at Bottom of Dock.		Length at Top of Dock.		Width of Entrance.		Depth of Water on Sill at O. W. H. Spring Tides.		Depth of Water at O. H. M. Neap Tides.		Remarks.
LIVERPOOL.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	
Canada lock and graving dock	501	0	..		100	0	26	0	19	0	
Huskisson lock and graving dock	396	0	..		80	0	24	9	17	9	
Sandon graving docks—											
No. 1, east	540	0	..		60	0	21	9	41	9	
„ 2, „	540	0	..		70	0	21	9	41	6	
„ 3, „	540	0	..		60	0	21	9	14	9	
„ 4, „	540	0	..		70	0	21	9	14	9	The total area and quay space of the Liverpool and Birkenhead Dock is as follows:—
„ 5, „	540	0	..		45	0	21	9	14	9	
„ 6, „	540	0	..		45	0	21	9	14	9	
Clarence graving docks—											
No. 1, outer gates	405	0	..		45	0	21	3	14	3	
„ 1, inner gates	291	0	..		45	0	18	9	11	9	
„ 2, outer gates	414	0	..		45	0	21	3	14	3	
„ 2, inner gates	288	0	..		32	10	18	9	11	9	
Canning graving docks—											
No. 1	441	0	..		35	9	19	11½	12	11½	
„ 2	488	0	..		35	9	18	3½	11	3½	
Brunswick graving docks—											
No. 1	399	0	..		42	0	20	9	13	9	
„ 2	399	0	..		43	0	20	9	13	9	
Queen's graving docks—											
No. 1	438	0	..		42	0	19	11¼	12	11¼	
„ 2	435	0	..		70	1	21	9	14	9	
BIRKENHEAD.											
No. 1, new dock } constructing	750	0	..		85	0	25	9	..		
„ 2, „ } constructing	750	0	..		50	0	25	9	..		
„ 1, dock } belonging to Laird Brothers	300	0	..		40	0	16	6	..		
„ 2, „ } belonging to Laird Brothers	180	0	..		45	0	16	6	..		
„ 3, „ } belonging to Laird Brothers	400	0	..		65	0	24	3	..		
„ 4, „ } belonging to Laird Brothers	440	0	..		85	0	20	6	..		
SOUTHAMPTON.											
Western dock	343	0	346	0	66	0	20	0	16	0	The eastern dock, made in 1854, is of brickwork, with Portland copings, and is stated to have cost 53,000*l*.
Middle dock	232	0	233	0	51	0	15	6	11	6	
Eastern dock	425	0	538	0	80	0	20	0	21	0	

Name of Dock.	Water Area.		Quay Space.	
	acres.	yds.	miles.	yds.
Liverpool ..	251	2664	18	763
Birkenhead ..	121	2869	5	786
Total.. ..	372	5533	23	1549

TABLE II.—PRINCIPAL DIMENSIONS of other DRY DOCKS of 300 Feet in Length, and upwards. 1862.

Name of Port.	Name of Dock.	Length over all.	Breadth of Entrance.	Depth of Water over Sill at O. H. W.
		feet.	feet.	feet.
Leith..	On the East Sands	400	71	23
Sunderland	Laing's	300	48	14
„	Commissioners	315	45	16·8
West Hartlepool	No. 1	375	60	16
„	No. 2	355	50	17
Great Grimsby	No. 1	400	70	19·6
Thames	Northfleet	400	74	19·6
„	New Crane	463·6	43·9	14·6
„	Union (upper)	331·6	39·8	15
„	Regent, No. 12	338	42·2	16
„	Green and Co.	342	62	18

TABLE II.—PRINCIPAL DIMENSIONS OF OTHER DRY DOCKS, &c.—*continued.*

Name of Port.	Name of Dock.	Length over all.	Breadth of Entrance.	Depth of Water over Sill at O. H. W.
		feet.	feet.	feet.
Thames	General Steam	328	40	14
Portsmouth	Camber Dock	345	50	17·3
Isle of Wight	Cowes	330	36	16·6
Plymouth	Mill Bay	367	80	27·6
Falmouth	No. 1	360	54	14
"	No. 2	400	90	20
Appledore	.. ..	326	43·3	15
Bristol	Great Western	300	45	13
"	Albion	380	38·6	13·6
"	Green	323	56	15
Cardiff	East Bute	435	48	18
Swansea	No. 3	300	36	16
Holyhead	.. ..	307	62·9	17
Greenock	Steel	361	47·8	16
"	Scott	300	45	15
"	Corporation	360	38	13
Dumbarton	.. ..	300	41	13
Glasgow	Tod and M'Gregor	500	56	18
Dublin	No. 1	400	70	18
Londonderry	.. ..	321	50	18
Cork	West Passage	390	86	24
"	Wheeler's	420	59	20
Trieste	Austrian Lloyd's	300	..	25
Bombay	Old Dock	613	51·9	16
"	Duncon Dock	600	63	16
Singapore	New Harbour	390	43	15
"	.. ..	450	62	18
Canton River	T. C. Couper	550	72	17
Amoy	.. ..	300	..	..
Australia	Cockatoo Island	306	58	20·6
"	Morts, in Waterview Bay ..	345	75	19
Rio Janeiro	Cobras Island	301	70	28

TABLE III.—FLOATING BASINS IN ENGLISH GOVERNMENT DOCKYARDS. 1862.

Name of Dockyard.	No. of Basins.	Water Area of Basins.	Lineal feet of Quay Space in each Basin.	Remarks.	Width.	Depth of Water on Sill at Ordinary High-water Spring Tides.	Depth of Water on Sill at Ordinary High-water Neap Tides.
		A. R. P.			ft.	ft. in.	ft. in.
Deptford ..	1	1 1 8	770		50	20 0	14 5
Woolwich	Outer basin	3 0 33	1250	No locks.	65	22 10	18 0
"	Inner basin	2 2 16	1250		65	21 0	16 2
Chatham ..	Nil.	.. ..	..		..	.. ..	.. ..
Sheerness	Great basin	3 2 5	1400		66	27 0	22 6
"	Small basin	1 0 23	850		50	20 6	16 0
"	Boat basin	1 1 7	551		100	26 0	21 0
Portsmouth	South basin	2 1 30	950	When Docks Nos. 7 and 10 are unoccupied they may be used as a lock 664 ft. long, with 27 ft. H.W. spring tides.	67	24 6	20 0
"	Steam basin	7 0 0	2190		80	25 0	21 0
Devonport	1	1 2 6	800	No lock.	74	30 6	26 8
Keyham ..	South basin	7 0 32	2150	Entrance lock 252 ft. 8 in. between caissons.	80	Outer entrance 36 0; Inner entrance 34 0	Outer entrance 21 6; Inner entrance 29 6
"	North basin	5 0 0	1350		80	25 0	20 6
Pembroke	Nil.	.. ..	..		..	.. ..	.. ..

Among the standard works relating to this subject we may mention the following;—Belidor, 'Architecture Hydraulique,' 4 vols., 4to, Paris, 1737-58. De Cessart, 'Description des Travaux Hydrauliques,' 4 vols., 4to, 1806-8. Elmes, J., 'Docks and Port of London and Liverpool,' folio, 1838. 'Life of T. Telford,' 4to, with folio Atlas of Plates, 1838. Sganzin, 'Cours de Construction,' 3 vols., 4to, and Atlas in folio, Paris, 1839-41. Minard, 'Cours de Construction des Ouvrages Hydrauliques des Ports de Mer,' 2 vols., 4to, Paris, 1841. Webster, T., 'The Port and Docks of Birkenhead,' 8vo, 1848. C. B. Stuart, 'The Naval Dry Docks of the United States,' 4to, New York, 1852. Sir J. Rennie, 'Theory, Formation, and Construction of British and Foreign Harbours,' 2 vols., folio, 1854. Gassend et Labour, 'Travaux Hydrauliques Maritimes,' folio, Marseille, 1861. Vuigner, 'Entrepôts de la Villette,' 4to, with Plates in folio, Paris, 1861. Roffiaen, 'Constructions Hydrauliques,' 3 vols., 8vo, Bruxelles, 1861-63. Humber's 'Record of Modern Engineering' for 1864 and 1866. See also numerous papers on Docks in the 'Minutes of the Institution of Civil Engineers,' 'Annales des Ponts et Chaussées,' 'Annales du Génie Civil,' and 'Engineering.'

See Anchor. Bond. Brickwork. Construction. Dam. Embankments. Keels and Coal Shipping. Lifts, Hoists, and Elevators. Lock Gates. Water-works.

DOG. Fr., *Clameau;* Ger., *Klammerhaken;* Ital., *Graffio, Grappa;* Span., *Grapa.*

A dog is a grappling iron, with a claw or claws, held by a chain or ropes, for fastening into woob or other heavy articles for the purpose of raising or moving them; or an iron with fangs for fastening a log in a saw-pit, or on the carriage of a saw-mill. A *dog* is a piece in machinery acting as a catch or clutch; especially the carrier of a lathe. An adjustable stop to change the motion of a machine tool is also called a dog.

DOLLY or DOLLY-TUB. Fr., *Cuve à rincer;* Ger., *Schlämmfass;* Ital., *Troguola;* Span., *Cubo de lavar.*

A dolly is a contrivance, turning on a vertical axis by a handle or winch, for facilitating the washing of ore; a stirrer.

DOME. Fr., *Dôme;* Ger., *Dom;* Ital., *Cupola;* Span., *Cúpula.*

In architecture, *dome* is a roof, or structure raised above the roof of an edifice, usually hemispherical in form, but sometimes the segment of a spheroid, ellipse, polygon, or other similar figure; a cupola.

The word is usually applied to any erection resembling the dome or cupola of a building, as the upper part of a furnace, and the like. A steam-dome. See Boiler. Furnaces. Locomotives.

DONKEY-ENGINE. Fr., *Machine à vapeur auxiliaire;* Ger., *Kleine Hülfsdampfmaschine;* Ital., *Macchina di alimentazione;* Span., *Máquina auxiliar.*

See Engine, *Varieties of.*

DOVETAIL. Fr., *Queue d'aronde; tenon à queue;* Ger., *Schwalbenschwanz.*

The manner of fastening boards or timber together by letting one piece, in the form of a dove's tail spread, or wedge reversed, into a corresponding cavity in another, so that it cannot be drawn out. *Dovetail Machine,* see Wood Working Machines.

DOWEL-PIN. Fr., *Goujon;* Ger., *Diebel oder Döbel;* Ital., *Perno;* Span., *Pasador.*

A dowel-pin may be of wood or metal, and is used for joining two pieces, as of wood, stones, or other material, by inserting part of its length into one piece, the rest of it entering a corresponding hole in the other, as in the heads of a cask. A *dowel-joint* is a joint made by means of a dowel.

DRAG-BAR or DRAW-BAR. Fr., *Barre d'attelages;* Ger., *Die Kupplestange;* Ital., *Sbarra d'attacco;* Span., *Vara motriza.*

A bar or link for attaching carriages together, or the moving power, as on railways; a coupling; called a *drag-link* and *draw-link.* A strong iron bolt or pin passing through the end of a *drag-bar,* and serving to fasten the coupling of a locomotive and tender or that of two carriages on a railway, is termed a drag-bolt. See Buffer. Railway Engineering.

DRAINAGE. Fr., *Drainage;* Ger., *Entwässerung;* Ital., *Fognatura;* Span., *Desagüe.*

Drainage is the mode in which the waters of a country pass off by its streams and rivers. The system of drains and their operation, by which water is removed from towns, railway beds, and other works. See Irrigation. Irrigation and Drainage. Pipes and Culverts. Pumps and Pumping Engines. Traps, *Drainage and Stench.*

Drainage of Mines.—The draining of a mine is one of the most important subjects in practical mining operations. The waters which come down the walls in drops gather into little streams, and these, united, form in extensive mines a considerable body. The quantity of water which may be furnished by a mine is not easily estimated beforehand. We can form some opinion as to the probable amount by reference to the kind of rock which we penetrate, and the capacity of the country for springs and wells; still this is no certain criterion, for the ground and rocks may be dry at the surface, and yet contain much water beneath. The rock may be covered by a layer of waterproof clay, which causes the surface to be wet and swampy; still, below it may be free from water, and a mine in such places perfectly dry. The elevation of a mine has an important influence upon the quantity of water which it may contain; most rock is accessible to water, which filtrates through its crevices, and gathers below. It will accumulate where the filtration is checked, and the rocks become saturated. Some rocks are remarkably dry, others contain much water. Volcanic rocks and limestone do not furnish much water to a mine; granite, also, is dry. The American copper mines at Lake Superior, which are chiefly in trap rock, are remarkably dry. Stratified rock, of either transition or secondary formation, is dry at the surface when the strata is inclined, but there is abundance of water in its lower portions. A deep mine in the gold region of the Southern States is always found to be very wet. Are the strata of rock horizontal, or nearly so, the quantity of water is greater in the higher parts of the hills than below. The coal region of the west of America furnishes sufficient evidence for this assertion. In all instances the quantity of water in a mine increases with its surface, that is, with the extent of its workings, apart from any other circumstance to influence it. When crevices are opened in the progress of work which

communicate with reservoirs of water in the interior of the rock, or pools at the surface, springs are formed which frequently add considerably to the waters of the mine. When a mine penetrates through a water-proof bed of clay, gypsum, or a layer of limestone, the water is in most cases more abundant below than above such stratum. In most of the mines in operation, where a circulation of air is freely admitted, the quantity of water is generally greater in summer, spring, and fall than in winter. When the interior of a mine is warmer than the atmosphere it will furnish moisture to the latter in its circulation through the mine; and when it is colder it will condense watery vapours of the air, which enter and increase the water. In all cases attention must be given to the manner in which the water penetrates, that its direct effect on the workmen may be avoided. It not only annoys them, but delays the work, and causes the mineral unnecessarily to be more expensive, by interfering with the comfort of those engaged in its extraction.

By Levels.—In forming a water-drain in the pavement of a drift or a gallery, it is necessary to pay some attention to its form. The walls of the drain also should be smooth; not that rough walls cause much friction, and diminish the velocity of the water, but because all the water issuing from the workrooms carries along some impurities—particles of rock, minerals, clay, and so on. This heavy matter will settle in rough, contracted, or crooked channels, more than in smooth and straight ones; this sediment causes pools of water, which soon overflow the pavement, rendering the mine wet, disagreeable, and injurious to the health of the workmen. These defects may be avoided in some measure by giving more fall to the drain, but it will not remove the evils resulting from an imperfect form of the channel. When it is possible, the water channel should be located on one side of the gallery or drift, rather than in the middle of the floor. When the drain is covered by timber or planks, or a roadway, it is not easily accessible, and sediment may accumulate and overflow a portion of the mine before it is observed and can be removed. If the channel is on one side, it may always be uncovered, and any obstruction is soon detected and removed. In all cases, no matter where the drain is located, it should be easy of access at any time. If parts of a drain are necessarily covered, where there is loose rock or gravel, it is advisable to make such parts spacious and of mason-work. Wooden culverts are liable to decay, particularly in a mine, and if the location of the culvert is inaccessible, it cannot easily be replaced without much disturbance. This is the more serious if the roadway extends over such culverts. The size and fall of a drain are calculated according to the laws regulating the motion of water in canals, but as there are many modifications of those laws, on account of obstructions, we are not justified in referring to them. The location, size, and fall of the drains are chiefly ascertained by observation. One foot fall in 100 ft. of length is considered sufficient in all instances; but as this, in long levels, causes a considerable loss in the depth of a mine, less fall is taken in many cases, and the size of the channels increased. One foot fall in 1000 ft. causes a considerable current; but the water must be clear, or the drain is liable to obstruction. A deep pool provided at the head of the drain will retain most of the mud issuing from the workrooms and roads, and pass the water free from sediment. Such pools may be cleared of their contents when filled, and serve a good purpose in draining a mine to its lowest depth.

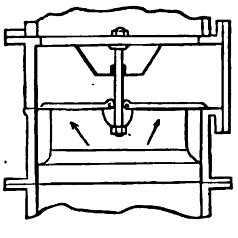
By Pumps.—Much ingenuity has been expended in the construction of pumps, in order to drain mines with the least possible expense. We shall not allude to the numerous forms of pumping machines which have been contrived in past times, nor to many of the imperfect means for pumping at present in use. We shall, however, describe that kind of machinery which is suitable to perform the most labour with the least expense. We have spoken of the hoisting of water by means of the rope and barrel in former pages, and shall confine our present remarks to pumps only. Notwithstanding the progress in mechanics and the construction of machinery, we find men who waste time and means on the invention of machinery for lifting water which never will successfully compete with well-constructed pumps. The principles governing the construction of pumps are not so generally observed as they should be. We state, for this reason, those laws which govern them.

Principles of the Pump.—There are three principal kinds of pumps—the sucking, the lifting, and the forcing pump; all these are used in mines, and often the whole of them in one set. The sucking pump consists essentially of the cylinder, the sucking pipe, the piston with its valve, and the sleeping valve at the lower extremity of the sucking pipe. When the lower end of the sucking pipe is immersed in a reservoir containing water, and the piston in the cylinder raised, the air contained in the space between the piston and the sleeping valve will expand, in proportion to the space evacuated by the piston. The density of the air without the pipe is greater than the density of that within, and pressing upon the water forces it into the pipe through the sucking valve so high as to produce an equilibrium between the external and internal air. As the air within is expanded in proportion to the space moved by the piston, an equal amount of water will be pressed into the pump to fill the space evacuated by the piston. The density of the air within and that without having become equal, the sleeping valve shuts by its own gravity, and prevents the flowing out of the water from the sucking pipe. The piston being now depressed, it will compress the air within; this causes the valve to open, and the air escapes through it. It is easily conceived that this play of the piston, when repeated, will raise the water to a certain height. It would raise it to an indefinite height if the air, or the gas formed by water in a vacuum, was not elastic. When the column of water thus raised is equal to the pressure of the atmosphere upon the vacuum, which height is indicated by the barometer, the piston may be raised, but it will produce only an elastic fluid. Either the water will evaporate and condense with the motion of the piston, or if there is any air in the pump it will expand and condense, following the motion of the piston. When nothing interferes with the motion of the water in the sucking pipe, and when the piston closes perfectly air-tight in the cylinder of the pump, the water may be raised to the average height of 33 ft.—the greatest height 34 ft. In practice this height never can be obtained, for the following reasons;—There is always a loss of height, because there is friction between the water and the pipe, which diminishes its motion. The sleeping valve always loses a little water as it shuts. The valve of the piston loses also from the same cause; and if the piston does not fit closely to the

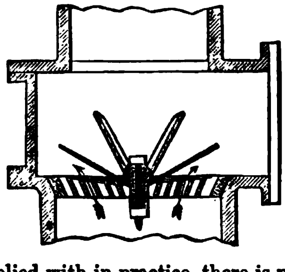
cylinder, there is a loss of height in the water. As smooth surfaces diminish friction, particularly between fluids and solid matter, it is of great importance to make the interior of pipes as smooth as possible. The loss of power in the sleeping valve is partly caused by the weight of the valve resisting the upward motion of the water, and partly by the impact of the valve when open, which prevents its quick return; and as the water suffers less from this cause, it will flow back before the valve is shut again. In both cases it is, therefore, advantageous to make the valve as light as possible, in order to oppose little or no obstacle to the motion of the water. The loss in power, or in the height of water in the pump, is here in proportion to the weight of the valve. If a sleeping valve covering 1 sq. in. weighed 15 lbs., it would not admit of the passage of any water, for that weight is equal to the pressure of the atmosphere. The weight of the valve causes therefore a loss in the proportion of its weight to that of the atmosphere. This loss is increased when we consider the impact of the valve. In the sleeping valve of a sucking pump there is, therefore, a considerable loss of power, which may be diminished or increased by altering the weight of the valve. The valve in the piston is not liable to the same objections as the sleeping valve. If the piston-valve is of great weight it will resist the motion of elastic fluids considerably; that of water it cannot affect, but by the friction which it causes in opposing its weight to the motion of the water. On the return of the piston, after having arrived at its culmination, a considerable loss is caused by the impact of the valve, which is greater in a heavy than in a light one. We see here, that the weight of a valve exerts considerable influence on the effect of a pump, particularly on that of a sucking pump.

The form of valves is of not less importance than their weight. A poppet-valve, in the form of a flat dish, is the most imperfect, because it is heavy, and does not afford a favourable form for the passage of water. The conical poppet-valve is better than the flat dish. It causes less disturbance in the current than the first valve, but it loses water because it is heavy and shuts slowly. Balls and cones are valves working well in small pumps, but are inapplicable in large ones. In pumps for mines hardly any other form of valve can be applied to advantage than that of the trap-valve. We allude to these particularly in the following remarks: valves should be as light as possible, for their weight must be lifted by the moving power before any water can pass. If the weight of a valve is great, the power required for raising it must also be considerable. The weight of the valve should be so regulated that its pressure upon its bearing may be small, and that it may be raised with the least power. When the valve is raised to its maximum, it should be as light as at the bottom, that its tendency to shut may not be retarded by impact. It must be quicker in its returning motion than the motion of the water. We find here that the horizontal position of a valve is contrary to principle, and that a perfectly vertical one is the best. The vertical valve has its disadvantages in connection with vertical pumps, because it always requires curves to be made in the pipes leading the water to and from it. What is here gained in the form of the valve is lost in the curve of the pipes. It is therefore of little advantage to employ vertical valves; the same may be said of inclined valves; and the question rests then with the horizontal trap-valve only. There is little doubt that this form is the most advantageous; but there are objections to the common metal valve, and also to the leather valve. The common metal valve, as represented in Fig. 2524, is a good one, but in heavy pumps it causes strong vibrations, and requires constant repair. This valve could be fastened to a spring, either of steel or india-rubber, so that it would be repulsed in every position, and nowhere at rest. When a valve is shut with pressure upon it, it must be so far lifted by a spring as to balance its own weight, and also some of the incumbent pressure of the water; but the spring must not open the valve. When it reaches its highest elevation a spring should force it back in advance of the returning water.

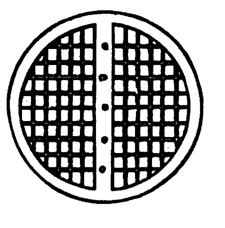
2524.



2525.



2526.

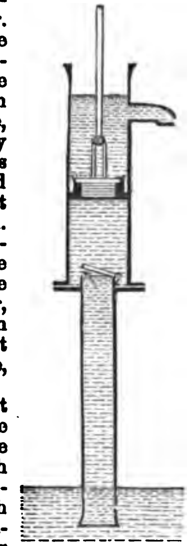


If these conditions could be complied with in practice, there is no doubt but any kind of valve affording a large passage would answer. Such suitable arrangements with valves may be possible; but we do not know of any which perform well and which we can recommend. Recently a most perfect form of valve for water-pumps of limited pressure has made its appearance. In Fig. 2525 we have represented one form of this valve, and in the course of this article we shall allude to some others. The valve is here formed simply by a sheet of vulcanized india-rubber, ¼ of an inch thick in small valves, and increasing to ½ an inch in thickness in large valves. The under-side, upon which the rubber rests, is represented in Fig. 2526. It is a cast-iron frame, round or square as the case may be, having a cross-bar in the middle of its area upon which the top and the rubber are screwed. The whole area of this plate consists of oblong openings for water, ¼ of an inch in width for small pumps, and from that to ½ an inch in width for large pumps, and a pressure of 15 or 20 lbs. to the square inch. The oblong holes in this plate may form a grate like that in a stove, or the bars may be divided into compartments by cross-bars, which in the meantime stiffen the plate and prevent its injury by slight causes. The sheet of india-rubber

which is screwed down in the middle, is easily lifted by the slightest pressure from below, and the openings in the bottom plate having a somewhat inclined direction, lift the valve very gently, and force it all at once to the full width against its angular support. It offers little or no resistance to the passing water by its own weight; it merely diminishes the passage for water. With the returning stroke of the pump, the water presses back upon the valve, passing through holes in the angular support. This valve causes less loss of power than the best valves of other forms; and gravity, which causes considerable contraction of the current of water in other cases, has little influence upon it. The small openings in the bottom plate occasion some loss of power by friction, but these holes may be polished, and in that case the loss is small. The greatest advantage of this valve is its soft bearing and perfectly close fit, which in mines is of considerable importance, because the waters of a mine often contain impurities and sand, which cause metal valves to close imperfectly. The simplicity of this valve is another recommendation which cannot be too highly appreciated in mines.

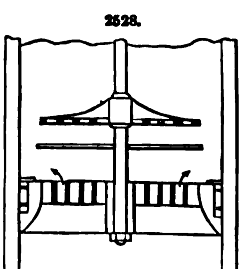
Lifting Pump.—When water is raised in the sucking pipe, which in practice should not be higher than 20 or 25 ft., and the piston is hollow and provided with valves, it will pass through the piston and ascend to any height we please. This height is limited only by the strength of material. In Fig. 2527 a lifting pump is represented, which shows the sleeping valve considerably above the lower extremity of the sucking pipe. This arrangement is necessary where the sucking pipe dips into an inaccessible pool of water. In such cases all that kind of machinery which is liable to need repairs must be easily accessible. It is not necessary to place the sleeping valve in the cylinder, or close to the piston, as shown in the drawing. It is sufficient if the valve is above the surface of the pool from which the pump draws its water. When the water in the lifting pump is raised to the height necessary for its discharge, a mouth-piece is appended to the vertical pipe, which may be directed to any point which well secures the flowing off of the water. In this case, as well as in that of the sleeping valve, the form of valve and its operation has a decided influence upon the effect of the pump. If the valve in the piston is heavy it will press upon the passing water, contract the passage for it, and cause friction. If the material of the pump, that is, piston-rod, levers, or other machinery connected with it, is elastic, or if any gas is in the water, or the water warm, the elasticity thus produced will cause an oscillation in the column of water above the piston, and this by its impact will occasion a considerable loss of power, particularly when the column of water is high. It is therefore necessary, in order to produce the best effect in a lifting pump, that the valves should be light and the machinery of the most rigid material. The above-mentioned valve, with iron pumps and machinery, is for these reasons the most perfect.

2527.



Of Pistons.—It is an essential condition in pumps that pistons should fit closely to the sides of the cylinder. This object cannot be obtained in square pumps, for which reason they are imperfect machines. Wooden cylinders are liable to abrasion, and consequently soon cause leakage at the piston, for which reason wood is a very imperfect material for pumps, even for those of low elevation. Wood is not strong nor close-grained; it is liable to filtration through its pores, and is therefore not suitable for making good pumps for high elevations. Pistons should fit tight in the cylinder, and afford as much opening for the passage of water as possible. In Fig. 2528 we represent a piston, which, according to our present knowledge, is the most perfect for a lifting pump of limited height. It is made of iron or brass, as the case may be, cast in one piece, and turned. The packing is produced by a series of steel rings, one laid on the top of the other, so as to fit closely between themselves; these rings are spring-hardened, and their diameter is somewhat larger than the diameter of the cylinder of the pump, so that the elasticity of the rings may cause a close fit in all parts. These rings are held at the face of the piston and in their places by a circular ring screwed firmly on the top of the piston, so as to give but very little play to them. The length of one of these rings is a little less than the circumference of the cylinder, and the open space thus caused in one of the rings is covered by the sound part of the next ring. The piston itself forms a grate, similar to that represented in Fig. 2525, with this difference, that here no solid bar traverses the area. It is entirely composed of small bars and oblong or rectangular spaces; the centre, containing the piston-rod and the circumference, shows the only solid parts. Above the piston, some inches distant, a round plate is screwed to the rod, which is permanently fixed in its place. This plate is also pierced with a number of round holes, or forms a grating of oblong apertures, similar to those in the piston. A sheet of vulcanized india-rubber, larger than the last-described plate, plays up and down with each stroke of the pump, resting either upon the piston, in the upward motion, or against the plate in the downward motion of the piston. In this manner the apertures in the piston are either shut or opened, according to the motion of the piston. The water thus passing through the apertures finds a circular space around the plate above, which is its passage. In this arrangement a considerable loss of power is caused by the descent of the india-rubber sheet. This loss is equal to a part of the distance traversed by the sheet, compared to the stroke of the pump. We may here employ the valve shown in Fig. 2525; but this diminishes the aperture in the piston by the solid bar in the diameter; still we are inclined to consider the form of Fig. 2526 superior to that of Fig. 2528.

2528.

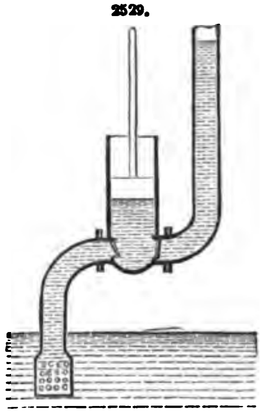


Force-Pump.—This kind of pump has no valve in the piston, by which it is chiefly distinguished

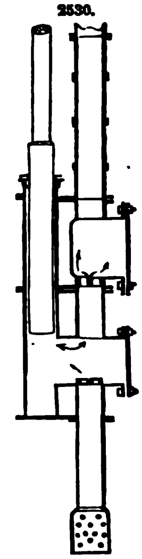
from the lifting pump. The piston is here solid, and the water is driven to some side pipe in which the lifting valve is fastened. In Fig. 2529 a common force-pump is shown. The solid piston is moving in a metal cylinder, which may be either of cast iron, brass, copper, or other metal. The water is sucked from the pool by its upward motion, and drawn into the cylinder; when it returns or descends, the water is forced out of the cylinder, and the sucking valve closes. The force-valve is now opened, which admits the water into a pipe, when it may be raised to the desired height.

We here very soon perceive what causes the chief loss of power in this pump. The water, in being drawn into the cylinder, has attained a certain direction in its motion, and when arrived at its maximum of speed and elevation, it is suddenly stopped and its motion changed. Water is almost inelastic, and any sudden alteration in the direction of its motion will create considerable resistance in its particles; it therefore reacts upon the piston, causing much loss of power. This loss increases more rapidly than the speed of the piston, and, perhaps, is not far from the cube of that speed. These pumps are not well adapted for use in mines. They require much repair, are expensive in the first cost, and also in consequence of loss of power.

2529.



2530.



Force-pumps similar in principle to the above, but different in construction, are extensively employed in English mines, and in water-works for supplying cities with water. This circumstance is a recommendation, but it does not make these pumps better; and if we blindly imitate what has been done by others, we may be led into the same error.

Fig. 2530 is of a pump of this kind. Instead of a piston a plunger is used, or second cylinder playing in the main cylinder, which latter is here a common strong cast-iron pipe. The only advantage this pump possesses over the above-mentioned force-pump is the absence of the piston-rod, which does away with the stuffing box for it, and also the friction caused by it. This, however, appears to be a small advantage, when we consider that the stuffing box for the pump, Fig. 2529, is a mere guide, and that a piston can be more accurately adjusted to the cylinder, so as to afford a close packing, than a plunger. The motion of the water is here the same, and a similar kind of action and reaction is produced, and the same loss of power must consequently ensue. These pumps are useful when an exceedingly slow motion of the piston is sufficient to raise the required amount of water. If a pump of this kind is chosen of sufficient dimensions to do the work with a slow motion, it will answer admirably well; but lifting pumps of large dimensions work as well, or even better. In leading pipes a long distance, or forcing water to a considerable height by one set of pumps, it is most useful to employ force-pumps, because when the piston-rod of the lifting pump descends through long pipes, its size is greatly increased, and the pipes must be made wide and strong. Force-pumps are therefore necessary in deep mines, where no room can be provided for a successive set of lifting pumps.

Pipes.—This is a subject of considerable interest in relation to the drainage of mines by pumps; for all the water raised by the pump must be conducted in suitable pipes to the desired height; and as the expense caused in their purchase is an important item, it would be well to ascertain the most profitable dimensions, in order to avoid unnecessary cost as well as imperfect work. When a pipe is filled with water, or any fluid, it presses upon the sides of the pipe with a force proportionate to the head. Pipes must be equally wide throughout their length; no contractions of any kind should be permitted; even bulgings are disadvantageous to the motion of water when imperfectly made. Curves, and particularly sharp angles, are highly objectionable. If such angles or knees cannot be avoided, it is necessary to make the radius for the curvature as long as possible. When such a curvature is not a part of a small circle, and not an acute angle, its influence on the motion of water in the pipe may be neglected; but in all cases where a pipe turns short, or doubles an angle, the loss in power must be taken into the calculation.

The friction of water in pipes is considerable, particularly under great velocities. If we call V the velocity with which water flows in straight pipes, L the length of the pipes, H the height of water or head, and R the radius of the pipe, the velocity in the pipe will be

$$V = 53\ 58 \times \sqrt{\frac{\frac{1}{2} R \times H}{L}}.$$

It follows from this that the loss in power increases with the square of the velocity, and that the least velocity is the most advantageous in practice. Frequently we find the velocities in water conduit pipes great, and of course a considerable loss of power is experienced. As a rule, we may state that water should not move with a greater velocity than 4 ft. per second in smooth and straight pipes. In curved pipes the velocity should be less, and in curved and contracted pipes still less. In the latter case the velocity should not exceed 2 ft. per second, and this should be reduced one-half if the pipe is longer than 100 diameters. We thus perceive that curves and contractions in pipes, to which roughness may be added, are imperfections which should be avoided by all means. They make it necessary to increase the width of the pipes, and thus the cost is increased.

The thickness required for pipes is determined by the pressure which may act upon their walls. The higher the water is in a vertical pipe, the greater is the pressure it will exert, and hence the strength of the pipe must be proportionate. As the tendency to rupture also increases with the diameter of the pipe, it follows that the larger the diameter the more metal will be required to withstand the pressure. If we call the diameters of two pipes D and d, the perpendicular height of water in the pipes H and h, and the thickness of the pipes T and t, we obtain the following equation, $T : t :: H \times D : h \times d$. When the value of one of these sizes for a certain material is known, we obtain the other very readily; that is, if we know that a certain pipe is strong enough to resist a certain pressure, we find the thickness of another pipe by substituting the values in the equation.

Experiments on various materials have shown that if we express E = T in twelfths of an inch, H in feet, and D in inches, the strength of material must be as the following numbers. For lead, $E = \frac{H \times D}{80}$; for cast iron, $E = \frac{H \times D}{200}$; and for wooden pipes with iron rings, $E = \frac{H \times D}{4}$. The thickness of a pipe is therefore as the height, and it should increase with the latter. When a set of pipes of a certain height are properly constructed, the upper part may be either thinner, or made of a weaker material in case it is cheaper. Cast-iron pipes are the most common in mines, and in fact are the only practicable pipes; but as this material is liable to great variation in quality, and also the thickness of cast iron cannot be depended upon for uniformity, we should increase the strength found by the above formula at least 25 or 30 per cent. We find, then, for a cast-iron pipe which is to bear a pressure of water 50 ft. high, and 6 in. in diameter, $E = \frac{50 \times 6}{200} = 1 \cdot 5$, or $\frac{1}{8}$ of an inch in thickness. Such a pipe cannot be cast, and we may assume that a cast-iron pipe of 6-in. bore must contain $\frac{1}{2}$ an inch of iron. This would afford strength for 200 ft. head, but as the formula indicates the extreme thickness, it is advisable not to extend pipes of $\frac{1}{2}$ an inch metal and 6-in. bore lower down than 150 ft. Each additional 40 ft. in depth requires $\frac{1}{8}$ of an inch additional thickness of metal.

The quantity of water furnished by a stroke of a pump is exactly equal to the space which is formed by the piston in the cylinder; that is, it is equivalent to the height of stroke multiplied by the area of the piston. If R is the radius of the piston, or bore of the cylinder, and S the stroke of the pump, the quantity of water furnished by each stroke $= R^2 \times 3 \cdot 1415 \times S$. The height to which the water is lifted has no influence upon this result. We assume in this formula that no water is lost by the valves, which is not the case, as we have seen above. As this loss depends upon the form of the valve, we cannot introduce a general coefficient which shall express it. The loss is often considerable, but as the water is not lifted which thus flows back, the diminution of power is not directly as the quantity, but a permanent part of it. Leakage between the piston and the cylinder is calculated on similar principles as the loss caused by the valves.

By actual experiment, it has been found that a man may lift 80 gallons of water in one minute 10 ft. high, by a good pump. He will, therefore, lift 160 gallons 5 ft. high, and 40 gallons 20 ft. high in the same time. The labour performed by men, animals, and machinery is always a product of time and power; and as a man or a machine can make advantageously but a certain number of motions in a certain time when applying their power, we are under the necessity of modifying the dimensions of a pump to the kind and form of motive power which we employ. A man may make from 60 to 80 motions per minute without over-exertion; the contractions of the muscles admit of such a number; and if a man, or a number of men, are employed to move a piston directly, or by a lever, the dimensions used must be such that the power of the men can be profitably applied. The above standard, that is, 80 gallons lifted 10 ft. in one minute, is a high result for a man's labour. It brings the unit of his power to $80 \times 8 \times 10 = 6400$ lbs. 1 ft. high in one minute, a result which is, for the average of human labour, by one-half too high. Here, however, as in all cases when we calculate the size of a pump, it is advantageous to assume a high standard of the unit power, because it will furnish a larger-sized pump than a low standard. We take thus for one man, 6400 lbs. lifted 1 ft. high in one minute; for the labour of an ox, 15,000; for that of a mule, 20,000; and for that of a horse, 30,000; and for a steam-engine or a water-wheel, 40,000 may be assumed. But as the elements by which the labour of such machines is estimated are exceedingly variable, we calculate the size of pumps according to the quantity of water which is to be lifted by them. A man may lift by his arms a certain load eighty times 2 ft. high, and if he is to lift 80 gallons 10 ft. high in a minute, he must lift 1 gallon 10 ft. high with every stroke, or every motion of his body; and as his hands can move but 2 ft. high, he must either apply a lever of 1 : 5, or lift the same quantity of water which is in the space of the 10 ft. in height, only 2 ft. high. We have seen above that water in pipes should not move with a greater velocity than 3 ft. per second, and for practical purposes 2 ft. are preferable to 3. When water is to be lifted 10 ft. high eighty times in a minute, this will give a velocity of $\frac{80 \times 10}{60} = 13\ 8$ ft. this divided by 2 furnishes a motion nearly seven times too rapid for water in pipes. The dimension of the pipe must be such as to contain 1 gallon of water in $1 \cdot 9$ ft. of length. If now the piston or the cylinder is equally wide with the pipe, the man must be placed so as to make 2 ft. motion in producing $1 \cdot 9$ ft. in the pump. The piston or cylinder of a pump is generally made larger in diameter than the pipes, because the valve contracts the passage in small pumps at least to one-half, and the cylinder is for these reasons one-half wider than the pipes, which causes it to have twice the area of the pipe. The velocity of the piston is therefore half that of the water in the pipes, and amounts to $\frac{1 \cdot 9}{2} = \cdot 95$ of a foot for each motion of the man. This $\cdot 95$ of a foot in length of the cylinder must contain 1 gallon of water,

and as 1 gallon is $\frac{1}{8}$ of a cubic foot, the diameter of the piston must be, when a gallon is 215 in., equal to 5 in. In this calculation we have not estimated the loss of water caused by the valves. If we assume that this is $\frac{1}{4}$ of the whole amount of water raised by each stroke, the diameter of the cylinder must be 6 in. in order to furnish the 80 gallons per minute. To this pump a lever must be applied, at the longest end of which the man works. As his motion is 2 ft., the leverage must be $\frac{\cdot 95}{2}$, or nearly 2 to 1.

This calculation is applied to a height of 10 ft., and if the motion is only 2 ft., the area of the piston must be five times as large, or the stroke five times increased. If the height to which the water must be raised is 20 ft., the area of the piston can be half of that for 10 ft., or the stroke of the pump must be diminished as the height increases. Ten times the height of water requires a piston ten times less, and ten times smaller pipes for the same amount of water. As the areas are as the squares of the diameters, the diameter of a pump is inversely as the square root of the heights, or as the square roots of the quantities of water. Generally, the diameters of pumps are $D : d :: \sqrt{H \times Q} : \sqrt{h \times q}$, in which formula D and d are diameters, H and h heights, Q and q quantities.

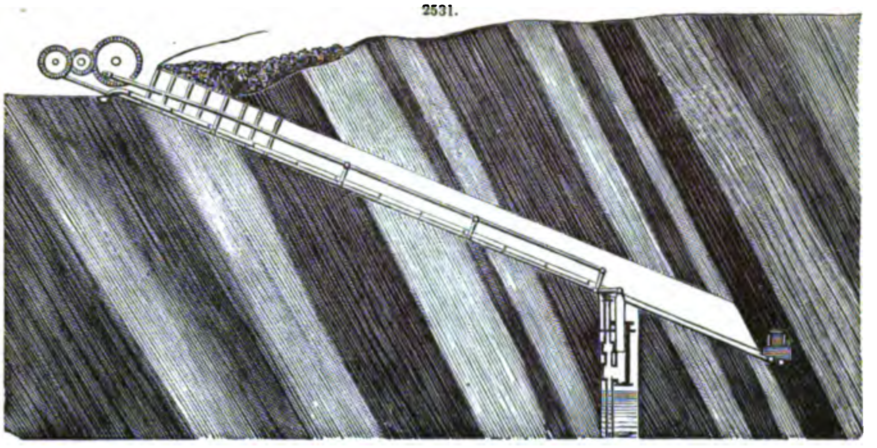
Loss of Power in Pumps.—The loss of power in a pump is caused by the friction of the piston on the sides of the cylinder; friction in the machinery which sets the piston in motion; and friction of water in the pipes and valves, and impact. The friction of a good metallic piston is not more than $\frac{1}{10}$ or $\frac{1}{12}$ of that of the power applied. Leather, hemp, or india-rubber cause $\frac{1}{4}$ loss of the power applied. The loss by friction between cast iron and wrought iron is $\frac{1}{6}$ of the moving power; it is less between brass and iron. Iron is very much corroded by the water of a mine, and if the first cost is not considered, it is advisable to line the pump cylinders or plungers with brass. The height of a piston should be at least $\frac{1}{2}$ of the diameter for metal packing; and for steel rings at least $\frac{1}{3}$ of that length should be the length of the packing. The friction caused by those parts of the machinery which set the piston in motion is equal to that of the piston itself, when well made. All other losses, added to the above, increase the loss of power—in a good pump to one-third of the power applied; in ordinary pumps to one-half; and in ill-constructed pumps to still more than one-half.

Length of Stroke.—There must be a certain limit of the length of stroke; it is asserted that in the largest pumps the stroke should not be more than 8 to 10 ft., and in hand-pumps proportionately less. We have seen on what basis the stroke of a pump is calculated for any power. That rule, however, would make the stroke in heavy pumps too short. A consideration which has most influence upon the length of stroke is the loss of water through the valves, which amounts to a considerable percentage in pumps with large valves and short stroke; and as this loss is uniform, and is the same for the long or the short stroke, it follows that a long stroke offers advantages in this respect. Another consideration is the size of the piston-rods; here the advantage is in favour of the long stroke, because the force required to move a small piston is not so great as that to move a large one, and the section of the rod may be smaller for these reasons. The only objection to the long stroke is the loss of power by increased friction in consequence of the diminished diameter. This loss, however, is not serious, considering the advantages of the long stroke. In this respect the force-pump with a plunger has advantages over the lifting pump, because it has no valve, and its size may be equal to that of the pipes, while that of the lifting pump must be twice as large as the latter, and in very large pumps at least $1\frac{1}{2}$ times that of the size of the pipes. We see no serious objections to any length of stroke, which is not limited by practical considerations. It may be urged that long cylinders cannot be bored correctly; this is no serious obstacle, for a plunger may be turned 40 ft. long and be perfectly straight and round; and if the advantages of a long stroke are so favourable as to outweigh those of the lifting pump over the force-pump, there is no objection to the latter.

Piston-Rods.—In large and also in deep pumps, the piston-rod is an object of particular attention, and various means have been suggested to overcome the objections to long rods. This circumstance alone is sufficient to balance all the advantages which may arise from an inclined shaft. The pumps may be set vertically in all cases, but the pump-rods are subject to the direction of the shafts and drifts. In inclined drifts or shafts, a pump-rod is generally composed of a number of short rods, which are supported and connected by levers which rest on axes. In Fig. 2531 is represented a system of such rods. These are made of wood, mounted at the ends with iron. The whole system of these rods plays thus with the oscillating motion of the crank, and as they must be necessarily heavy, a great deal of power is lost by friction. Iron rods cannot be applied in these cases, because the distance from one support to the other must be made as long as possible. This is often, with wooden rods, 50 ft., and from that to 100 ft., for one length between two supports. An oscillating motion of any power may thus be carried to a considerable distance; it has been extended in old mines to many thousands of feet. In vertical shafts, similar pump-rods are used; of course these are not supported at certain lengths; the wood is screwed together, and if the depth of the mine is great, the rods are supported by chains slung over pulleys. In Figs. 2532 to 2534, we show the arrangement as it is commonly made. The pump-rods are of wood, carefully spliced, and secured by layers of timber and iron hoops. The sticks of which the whole length is composed are carefully straightened, hewn, and planed. We represent in the engraving three parts of the whole of a pump,—an upper part, Fig. 2532; a middle part, Fig. 2533; and a lower part, Fig. 2534. The mine may be of any depth; the form of the upper and the lower parts is always the same; the middle part is made longer or shorter, or the number of pulleys increased, as circumstances may demand. We see here the lower part of the whole set of pumps consists of a sucking and lifting pump, all the other parts, however many there may be, are force-pumps with plungers. The weight of the whole length of the piston-rods, plungers, and all the moving appendages, is here equal to the column of water, or to the united sectional surfaces of the plungers, inclusive of the friction of

the water in the pumps, and the friction in the machinery of the piston-rod. Hence the weight of the piston-rod will in its descent set all the pumps in operation, and the engine which drives the

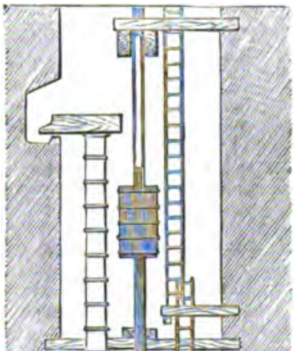
2531.



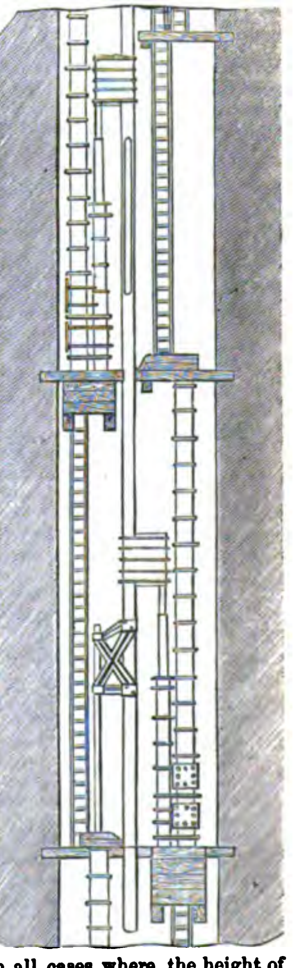
pumps has merely to lift the piston-rods. This arrangement is judicious, for by it the rods are prevented from receiving the pushing force, and it provides against vibrations. The rod has here to sustain the direct strain only; and as wood as well as wrought iron is strongest when the force is directly applied, the material is in this position used to the best advantage. Wooden pump-rods are in this case, as in most others, preferable to metal rods. We shall endeavour to explain the cause of this hereafter.

In the construction of pumps for deep mines, pump-rods form a most important particular. They frequently are the only cause why a succession of pumps is set one above the other, and if we endeavour to limit the number of pumps, we lose the advantage arising from working the pump by the gravity of the rod, or we are exposed to injurious vibrations. If we apply lifting pumps, we may raise a column of water to any height by one pump, but this requires generally ponderous piston-rods, and is soon abandoned, and the sets of pumps multiplied. This division of the whole height of a pump into various sets is in many respects advantageous; the rods and the pipes may be lighter, and all the machinery connected with them, so that a number of pumps of a certain height each is preferable to one pump extending the whole height. In all cases where the height of one pump exceeds the advantages which may be derived from the peculiarity of the material of

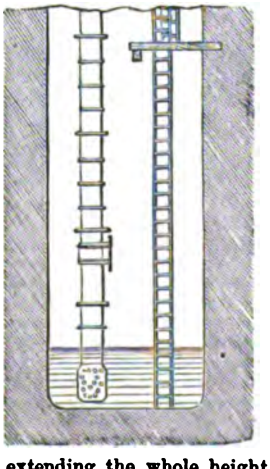
2532.



2533.



2534.

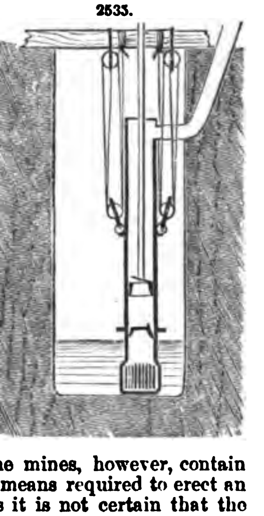


which the pump is constructed, we limit that height to the nature of the material. We have seen that cast-iron pipes of 6 in. in diameter cannot be cast thinner than ½ an inch. If we need pipes only 6 in. wide, it would be disadvantageous to take a less height for the pump than 150 ft., because cast iron of that thickness can bear the pressure of a column of water of that height. If the pipes are wider than 6 in., the height of the pumps must be diminished accordingly, or the thickness of metal increased. If the pump or pipe is 12 in. wide, the height can be only 75 ft., or the thickness of the iron must be 1 in. Are the pumps narrower than 6 in. in diameter, either the iron can be made thinner, or, which is preferable, the height of the pumps may be increased.

One set of pumps is not often made higher than 150 ft., and from that to 100 ft. Each set throws its water into a firmly-placed cistern, from which the next pump sucks it. The lowest set, or the lifting pump, is generally not very high, and seldom exceeds 40 or 50 ft. The water in mines contains always a large quantity of air, which is mostly thrown out at the first pump: if this air is permitted to pass into the next pump, an equal volume of water is replaced by air, and of course the pump does not throw so much water as calculated. The sucking part of the pump is for these reasons never very high, and often it does not exceed 8 or 10 ft. The pumps are lodged and fastened upon a part of the rock. In a vertical pit, this is excavated so wide as to admit the passage of the platforms and of the workmen; but the remainder of the space of the section is appropriated to the pumps. Such a projection extends often 3 ft. into the pit, which forms, when in solid rock, a strong chin or bracket. The cistern rests partly on this bracket: the largest part of it, however, is sunk into the rock, a chamber having been excavated, with a floor on a level with the upper edge of the bracket. The bracket is generally some few feet high, and the shaft below resumes its usual form. The division of a pump in deep pits has also other advantages, one of which is that of collecting the water from each height of a set of pumps. The water in coming down from above one of the cisterns is gathered into it by means of an inclined gutter cut in the rock, or fastened to it. If the depth of the mine is divided into various work-levels, the water from each level is gathered in the next cistern below it.

Setting of a Pump.—Whenever a shaft is sunk to such a depth as to require a pump; that is, if the use of the whim and the barrel cannot keep the mine dry, the first or lowest set of pumps is let down upon the bottom of the pit. It consists of a cylinder with a valve-piston, and forms a sucking and lifting pump. This is of a size sufficient for the whole depth of the mine, and when once lowered it is never raised again. It is suspended on two pairs of blocks or pulleys, as represented in Fig. 2535. It is well fastened above, so as to secure it firmly in its place, and the piston-rod, which is in the interior of the straight pipes, is secured by a stuffing box. The piston lifts the water high above the top of the pump. At the upper part of the highest pipe a leather hose is attached, in which the water is either conducted to the nearest cistern, in case there is already a set of pumps fastened in the shaft, or to the surface, and discharged. This flexible hose allows the pump to be gradually lowered, as the bottom of the pit is sunk deeper by the workmen. In some cases the lower part of the pump—that is, the pipe with the basket—is replaced by a piece of strong leather hose, which is flexible, and may be put into any pool in the bottom of the pit, the workmen having previously made a cavity for gathering the water. In the drawing we represent the basket which dips into the water as composed of parallel rods, instead of round holes bored into the pipe. These oblong cavities do not fill so soon with débris of rock, and may be made narrower, affording still a larger passage for water than round apertures. In some instances the lowest part of the pipe is provided with a trumpet-shaped mouth, and a basket is attached to the pipe. The latter arrangement offers more basket surface, and is not so liable to be filled by particles of rock as the pierced pipe.

2535.

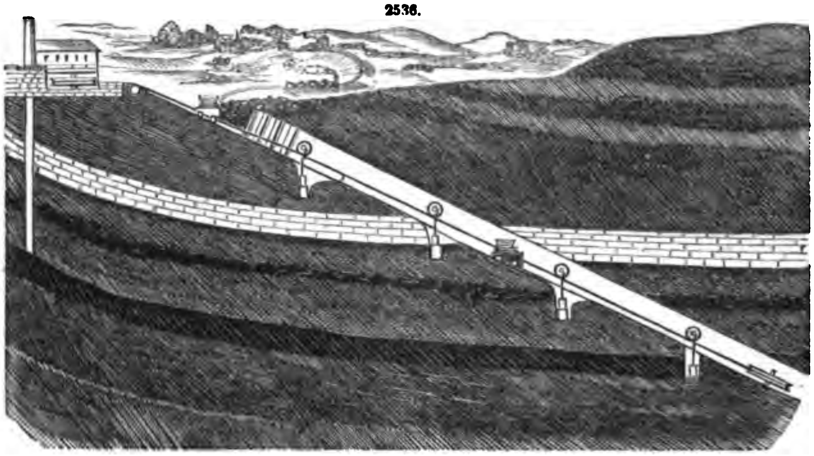


Proposal of a New Method for Setting Pumps.—Most of the mines in the United States are not very deep, seldom more than 300 or 400 ft. Those of the latter depth are very few; most of them also are little below the water levels of the country, and many years may elapse before miners are compelled to extract mineral from deep ones. Many of the mines, however, contain large quantities of water, which prevents the working of them. The means required to erect an expensive pumping machine are comparatively great, and in most cases it is not certain that the mines will repay the expenses incurred; we therefore propose the following arrangement, which may in some instances facilitate the working of a profitable mine, now dead for want of means to construct a sufficient number of pumps.

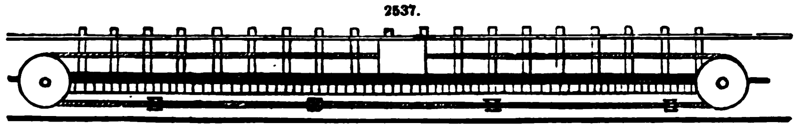
Any mine may be worked by means of inclined shafts, and if they interfere with the erection of common pumps, and also with the hoisting apparatus, the difficulty may be remedied if the machinery is adapted to the peculiar form of the shaft. The excavating of an inclined drift or shaft is on the whole not more expensive than that of a vertical shaft; its length is greater, but the work may be performed with more ease and on lower terms for the removal of the same amount of rock. We represent in Figs. 2536, 2537, this system, and shall point out its advantages presently. Fig. 2536 shows an inclined shaft, whose slope may be more or less than 45°, but in all instances it should be sufficient to admit of the use of carriage platforms on which the cars from the galleries may be driven and hoisted as they come from the workrooms. The shaft has the width for one track of railroad, calculated to carry as much mineral as the mine may furnish; the platform being of sufficient size for taking as many cars as may be required for one trip. The hoisting is therefore done all on one track, and as a wire rope may be made sufficiently strong for any load, no matter how heavy, there is no objection to its hoisting all the mineral on one platform. The platform thus travels up and down on the same track, which causes apparently a loss of power, but not in

reality, as we shall see presently. The wire rope which passes around a guiding pulley below, is wound upon a drum on the top of the slope, or it may be conducted over a grooved pulley and

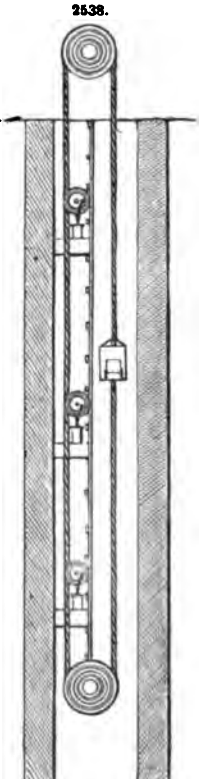
2536.



2537.



2538.



worked by adhesion. A drum connected with the engine at the top, upon which the rope winds, has great advantages in respect to the durability of the rope, but where economy in first cost is an object to the miner, the grooved pulley may answer the purpose. One half of the shaft is allotted to the pumps and the stairs by which the miners descend and ascend. That part in which the pumps are distributed is more distinctly shown in Fig. 2537. We see there the wagon-track for the platform, and a number of pumps distributed along the second rope. At each pump is a pulley, around which the wire rope is slung, and this drives the pump. We represent in the drawing the pumps as sunk in the ground; there is no necessity for doing this; they may be laid on the floor of the drift or posted upright. As to rotary pumps, any kind which will furnish most water by the application of the smallest power is right. One condition, however, must be observed in determining on the plan for these pumps; that is, the rope travels backwards and forwards, and the pumps must work to both motions. Pumps which are driven by a crank offer no difficulty in that respect, although some kinds of rotary pumps work only in one direction. Any number of pumps may be employed with the greatest facility; and if expense is a consideration, the cheapest kind of pumps, those which throw water but 40 or 50 ft. high, may be used. If, in the course of the work, it is found that the pumps in operation are too small for the labour assigned to them, an addition to their number may be made instead of throwing the old pumps out. The leading principle is here to employ a large number of small pumps, of limited lift, instead of only a few reaching to a great depth, and lifting with each set to the height of 150 or 200 ft.

This system of working a mine is not confined to the slope; it may be used to equal advantage in the vertical pit or horizontal drift, as is shown in the following figure. The inclined pit is, however, cheaper than the vertical one; and as the objections to it are removed by this kind of machinery, we consider it to be the most advantageous form for hoisting, pumping, and ventilation. If this inclined pit is of the same size as a vertical pit, and if its length is greater than the latter, it may be excavated cheaper, particularly in stratified rock. A cubic yard of a vertical pit will cost at least twice the price of a cubic yard in the horizontal drift; and if the work in the slope cannot be done quite as cheap as in the drift, it will cost but little more. In all instances there is not much more room required in the slope than in the shaft.

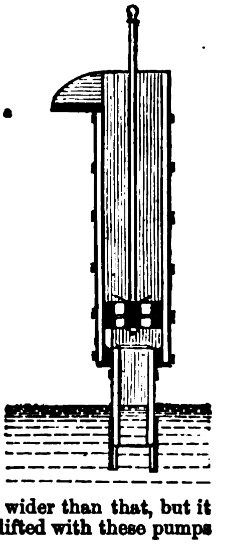
In Fig. 2538 we represent the same principle adapted to a vertical shaft. In fact it does not make any essential difference if the system is applied either to the one or the other form of entrance. The chief objection to the vertical shaft is its admitting only a small platform, which, even if it takes as much mineral as the large platform of the slope, or that of the drift, it requires more time to unload. Assuming that in most, if not in all cases, the dog-cart is the most profitable in our mines of limited extent, that

cart must be admitted upon the platform at once, and also easily removed. When a large quantity of mineral, such as coal, is to be hoisted, a number of carts must find room at once on the platform, without being much crowded. It is not objectionable to make the platform of an inclined plane in the form of steps, so that it may afford a large area. To this arrangement there is, however, some objection in the vertical pit, because it would require a high tower to bring all the platforms, if more than one, above ground and unload them with dispatch. It needs scarcely to be stated that the rope which drives the pumps requires no greater strength than is necessary for that purpose. Either rope, it may be that for hoisting or for pumping, has its peculiar size. Both ropes need not be of equal size.

In respect to ventilation, this system offers peculiar advantages. Where no air-shaft can be located conveniently a blower may be placed at the bottom of the pit, and driven by the guide-pulley. The changing rotation of that pulley is no objection, for if a common fan-blower with radial vanes is employed, it does not make much difference which way it is driven. The blower is here at the best place in the whole mine. The air is here heaviest and of most force.

Various Forms of Pumps.—In conclusion, we furnish various forms of pumps now in use, and select such specimens as are most suitable to secure the desired effect with the least labour and expense. When water is to be lifted only 2 or 3 ft., the use of the common water-bucket is about as profitable as any instrument we could apply, particularly if no other motive power but that of man can be employed. If circumstances admit of the use of animal power, or water, or steam-engines, these of course are preferable to human labour, because they are cheaper. If a unit of power is represented in that of a horse-power in the steam-engine, which is by general agreement 33,000 lbs. lifted 1 ft. high per minute, and we calculate the cost of that unit in the various means by which machinery or pumps may be driven, we find the expenses for one hour as follows;—The cost of that unit of power in a water-wheel is very small, and amounts to the interest on the capital invested. If we neglect this item in all cases, which properly may be done, because it is variable and depends chiefly on localities, we find the cost of one horse-power in the water-wheel per hour a mere nominal sum. The same unit causes in a Cornish steam-engine the use of 3·5 lbs. of coal, to which the wages of engineer and fireman, and also the cost of repairs must be added, which may increase the expense about 1 cent per hour in large engines, and 2 cents in small engines. The price of coal is very variable in the United States, and so must be the cost of power in a steam-engine. A common engine with crank and fly-wheel, well made, and of at least 100 horse-power, will consume 5 lbs. of coal for the same power. A steam-engine of less power and high pressure, will consume 10 lbs.; and a small engine, of from 15 to 20 lbs. of coal per hour and per horse-power. The actual cost may be little more than 1 cent in the best engines, and about 10 cents in small engines and with high-priced fuel. A unit of power will cost in a horse from 20 to 50 cents; in the ox and mule about the same. Human labour will cost at least $1 for the amount done by the water-wheel for nothing, and by a good steam-engine for 1 cent. As the lifting of water is an operation which requires constant and in most cases great power, it is well worth while to give close attention to the engine which drives the pumps, and to the construction of the pumps also.

2539.

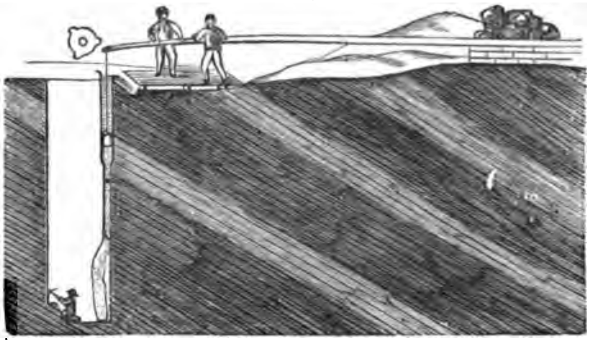


If water is to be lifted only 10 or 12 ft. high, wooden pumps may answer the purpose; but as in this instance a saving in the cost of labour is of importance, the common wooden pump will not answer. Where only a small quantity of water is to be lifted, the common hand-whim or horse-whim is used, together with the barrel or kibbel, the use of which is limited to small mines or small quantities of water. A wooden pump is represented in Fig. 2539. It is constructed of 2-in. plank, and well provided with iron hoops for securing its joints. The lower part of the pump has a short sucking pipe, and some projections to sustain the lower extremity above the bottom of the pit. This sucking pipe, which may be 2 ft. long, is required to prevent fragments of stone from entering the valve and pump, because these will drop in the downward stroke of the pump when the water is at rest in the sucking pipe. The piston is a block of wood through which some auger-holes are bored. The piston-rod may be either of iron or wood; in the latter case it should be mounted with iron, in order to fasten it firmly to the piston. The valves are made of sole-leather, or, what is better, vulcanized india-rubber, provided on the upper side with a piece of sheet metal, riveted to the leather. The latter must be large enough to cover the whole area of the opening, to prevent injury to the leather. These pumps may be made 12 in. square inside, and even wider than that, but it is not profitable to make them less than 6 in. square. Water cannot well be lifted with these pumps to a greater height than 12 ft.

Spring-Poles for Pumps.—The means by which to cause the oscillating motion of a pump piston are various. The crank appears to create the most imperfect motion, for any pump to which it is applied furnishes less water than when other means are used. Human labour is generally applied to a lever of unequal lengths, on the longer part of which the moving power acts. This appears to be the most profitable form of applying the power to common pumps. On board the flat-boats, on the Western rivers, a kind of square pump is in use, which is very imperfect so far as the pump itself and valves are concerned, but a man may throw a large quantity of water with one of them. These pumps are provided with a spring-pole instead of a lever. We have found this to be an efficient means of conducting power to the pump, and consider it the cause of the large quantity of water raised. In adapting spring-poles to other pumps, the quantity of water raised is greatly augmented. The arrangement is in this case as represented in Fig. 2540. The rationale of this operation is as follows. When the elastic spring-pole is depressed with the piston to the lowest

point, the depressing force relaxes, and the pole returns to its former position, lifting the whole column of water by its elasticity. The change of motion is here very sudden, and tends to close the valves quickly, so that not much water can return through them. The rod, in moving the column of water with a great velocity, will mount to a higher point than actually belongs to it when at rest, and return from that elevation quickly. This returning motion may be assisted by the moving power. The sucking valve also is here forced to shut quickly for the same reason as the piston-valve. Another advantage may be found in the mode of applying the muscular powers; the upward stroke being performed by the rod, the muscles of the men are free to relax and gather fresh energy for the next stroke. We allude to this as an important aid in the motion of pistons in pumps. This spring-pole produces quite the reverse of the crank motion, when the latter is converted into linear motion. A quick change is caused by the elastic spring-pole, and a slow change by the crank. If the same power and pump furnish more water when worked by means of the first than by the latter, the principle involved in the motion of the first must be more correct than in the latter. This applies, of course, to pumps generally. In constructing pumps, and particularly the connection between the moving power and the piston, we should apply this aid in all cases. When the pump is driven by horses, oxen, a steam-engine, or a water-wheel, which power cannot be employed like that of intelligent men, we should apply that force to an elastic medium capable of producing a similar motion as the spring-pole. We indicate in the drawing the application of a uniform rotary motion, by means of cams to the piston-rod itself. This may be adapted to a communicating lever, or a prolongation of the spring-pole; but in no case will it work to advantage when applied to the spring-pole itself, at a place between the pump and the fixed point of the spring-pole. It is not necessary, and is also impracticable, to employ a spring-pole at large and permanent pumps, but by whatever means the motion is produced, it should be of this nature. The elastic medium has an improving and regulating effect upon the action of a pump. In attaching steam-power to a pump it is therefore proper to dispense with the fly-wheel, and apply the steam directly to the piston-rod, or a rigid connection with it. We observe here that an elastic piston-rod will be productive of the reverse effect produced by the spring-pole.

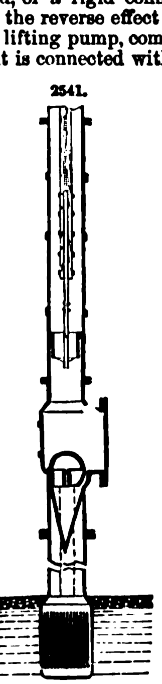
2540.



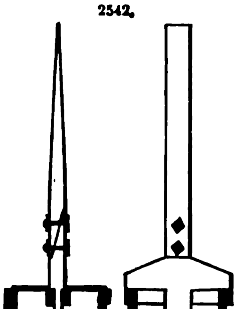
In Fig. 2541 we represent a lifting pump, composed of iron pipes, and a wooden piston-rod; the latter is shod with iron, where it is connected with the piston. In Fig. 2542 are two sections of the piston, the packing of which may be taken out and put in from below, so that both sucking valve, lifting valve, and packing are accessible from the one valve chamber, and the piston rod need not be drawn when anything happens to the piston, or when the packing or valve is to be replaced. The packing is here protected against coarse sand and stones by the upper part of the metallic piston, which is made so large in diameter as to close very near to the sides of the pump. A strong iron hoop is bent over the sucking valve in the form of a protecting arc, in order to prevent injury to that valve by the piston, in case it should drop.

In Fig. 2543, we represent a forcing pump with a descending plunger, which may be considered a specimen of a good pump of this kind. The weight of the plunger, which may be modified by inserted weights and piston-rod, is here calculated to force the water into the lifting pipe. As the changes of such a heavy rod cannot be aided with a spring-pole, the valves must not open too far or they will be liable to lose much water.

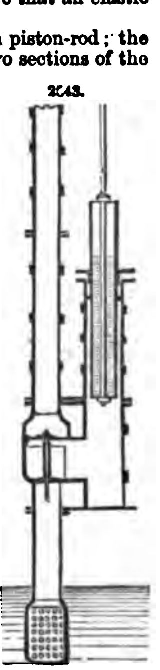
2541.



2542.



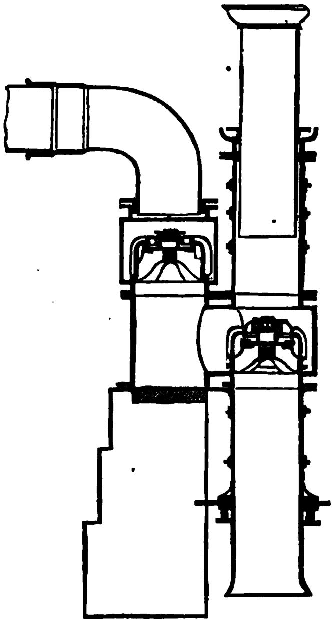
2543.



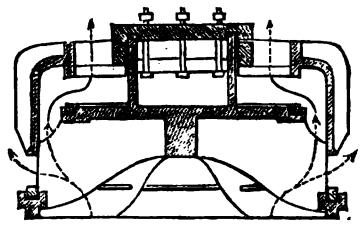
The packing of the stuffing box may be hemp; vulcanized india-rubber is however better; leather is frequently used, but anti-friction metal or brass is preferable to either. The sucking pipe is never very long in these cases, that it may not lose much water by the liberation of air from the water.

Fig. 2544 is a drawing of a pump of the largest kind; the sucking valve is represented as being open, and the forcing valve shut; the piston is half-stroke, and ascending. This kind of pump works very advantageously owing chiefly to the peculiar arrangements in the valves. As this is an object of importance, we furnish the valve in various figures, which represent sections and views of it. Fig. 2545 shows a vertical section of the valve when open; the movable part, as is seen, rises to a small height only, and consequently shuts very quickly, affording a large passage for

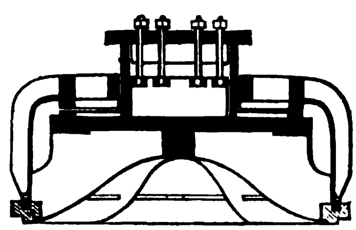
2544.



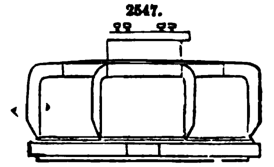
2545.



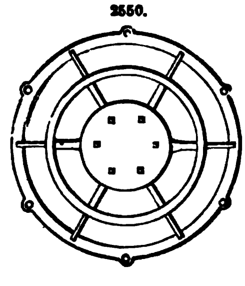
2546.



2547.



2550.



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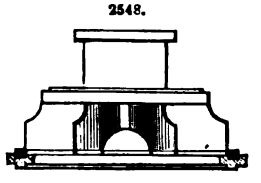
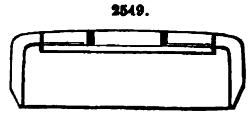


2549.



water. In Fig. 2546 the valve is represented as shut. Fig. 2547 shows a view of the valve shut. Fig. 2548 is a section of the immovable part of the valve; and Fig. 2549 a section of the cap or valve itself. Fig. 2550 is a view from above. See Archimedian Screw. Artesian Wells. Boring and Blasting. Coal Mining. Construction. Copper. Float Water-wheels. Iron. Lead. Pumps and Pumping Engines. Tin. Valves.

DRAINAGE and STENCH TRAPS. Fr., *Puisards d'écoulement;* Ger., *Senkgruben;* Ital., *Valvola a tenuta d'aria;* Span., *Aparatos inodoros.*

See Traps, *Drainage and Stench.*

DRAWBRIDGE. Fr., *Pont-levis;* Ger., *Zugbrücke;* Ital., *Ponte levatoio;* Span., *Puente levadizo.*

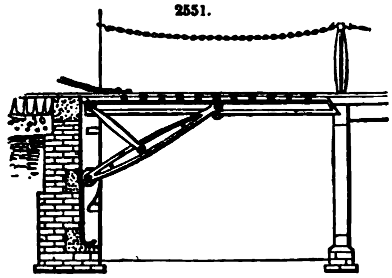
A bridge of which either a part or the whole is made to be raised up, let down, or drawn or turned aside, is termed a *drawbridge.* The movable portion, or draw, is called, specifically, a bascule, balance, or lifting bridge, a turning, swivel, or swing bridge, or a rolling bridge, according as it turns on a hinge vertically, or on a pivot horizontally, or is pushed lengthwise on friction rollers.

The bridge shown in Figs. 2551 to 2554 is a rolling drawbridge, designed by C. T. Guthrie, for military purposes, for which it is well adapted. However, drawbridges for civil use constructed on this principle may be applied with much advantage.

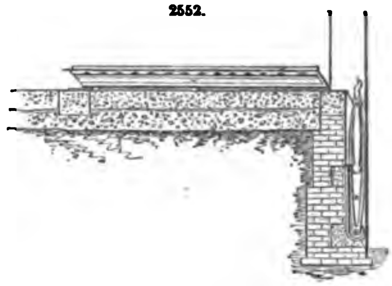
The bridge is formed of two rolled or built wrought-iron girders, covered with planking, and supported at their centres by cast-iron struts; these are suspended by links in such a manner that while the upper ends of the struts accompany the bridge in its motion, their lower ends travel nearly vertically against the escarp wall. Thus their centres of suspension, which are also their centres of gravity, descend in circular arcs, whilst their upper ends which support the bridge ascend in arcs of a certain curve. The weight of the struts is thus opposed to the weight of the bridge, and the position of their points of suspension, their angle of inclination, and weight, and

the form of the racers against which their lower ends travel, are such that they balance the weight of the bridge in every possible position, without any waste of material. It follows from this that the force required to move the bridge is exceedingly small, being due only to the friction on the axles.

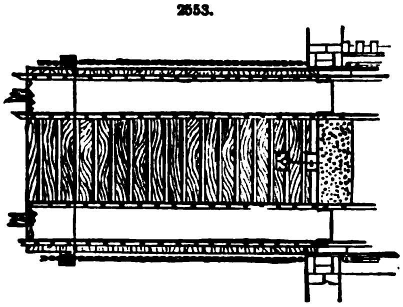
2551.



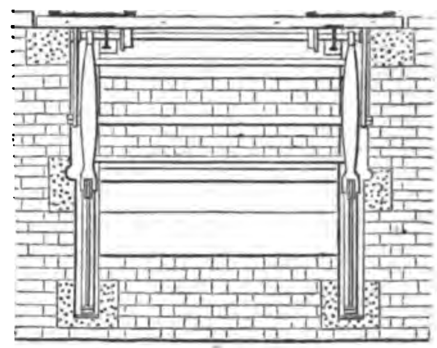
2552.



2553.

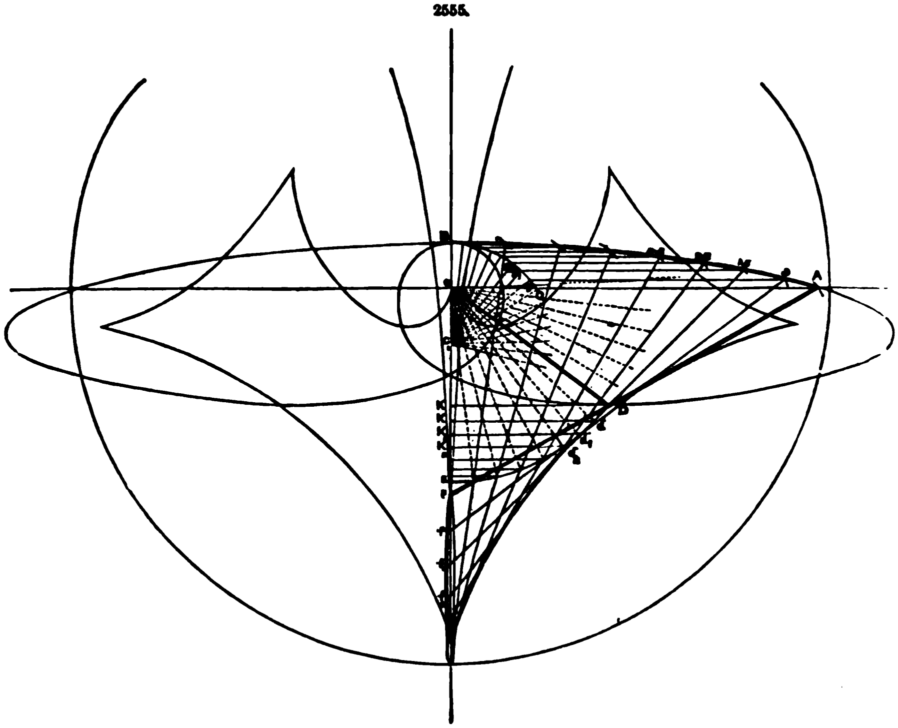


2554.



The diagram, Fig. 2555, is to illustrate the method of finding the proper curve to give the racers, in order that the bridge should be balanced in every position; it also shows the path of the

2555.



centre of gravity of the bridge. It is unnecessary for any practical purpose to find the equation to these curves; suffice it to say that the first is compounded of the equation of a circle and its diameter, and the second of the equation of an ellipse and its diameter, and that while one centre is moving diametrically, the other is moving perimetrically.

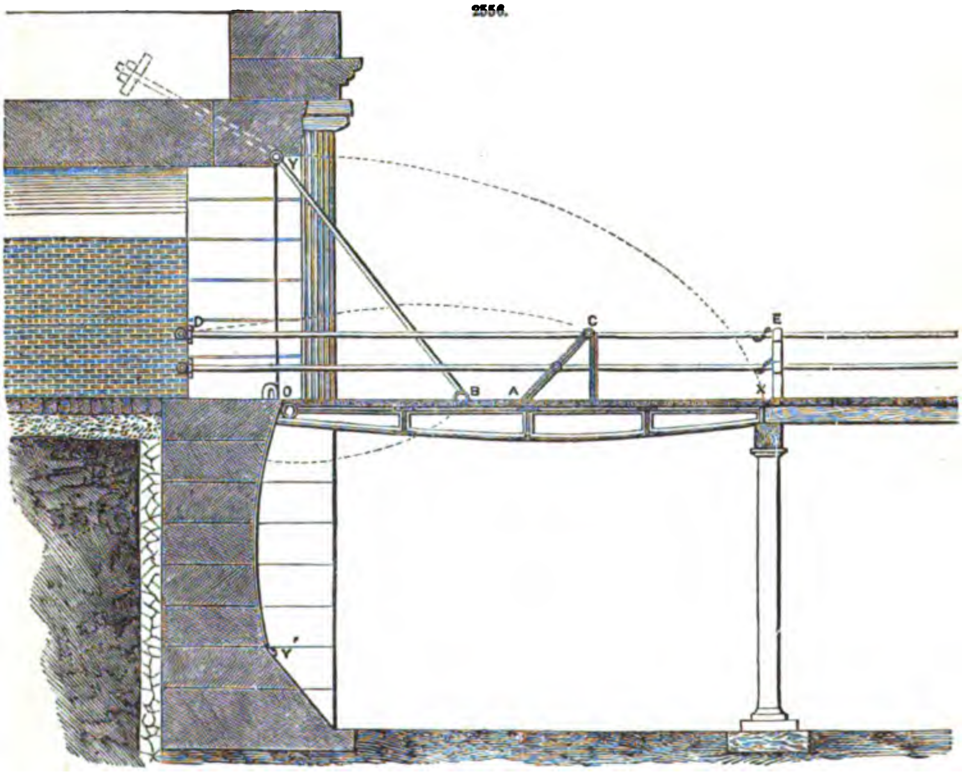
The constructive method of finding the proper curve for the racers is as follows;—

While the centre of the bridge ascends in the arc A B, the centres of the struts descend through the arc D E. Now as the struts are to balance the bridge in every position, the relative vertical rate of motion of their centres must be inversely as their respective weights. Draw the horizontal lines A C, D K, then the weight of the bridge is to the weight of the struts as K E is to C B, and the centre of the bridge must pass vertically from C to B at the same relative rate at which the centre of the struts passes from K to E. Draw the sector B G C_1, similar to the sector C D E, and divide the arcs B G and D E into the same number of equal parts, and draw the horizontal lines $g\,a$, $g_1\,a_1$, $g_2\,a_2$, and so on, $d\,k$, $d_1\,k_1$, and so on. Then it is evident that if the centre of the bridge rises successively to the levels g, g_1, g_2, and so on, while the centre of the struts falls to the levels d, d_1, d_2, and so on, respectively, the conditions of equilibrium will be fulfilled. So from the point d, with a radius D A, describe an arc cutting the line $g\,a$ in a, join $a\,d$, and from d, with a radius D F, strike an arc cutting $a\,d$ produced in f, then f is a point in the required curve. Similarly f_1, f_2, f_3, and so on, may be found. The part of the curve taken for the racers deviates very slightly from a straight line.

The most convenient proportion to make the several parts of a bridge of this description, which may vary in length from 10 to 40 ft., is perhaps to give the struts an inclination of 30°; to make them half the weight of the bridge, and to cause their centre of gravity to descend, as the bridge is rolled back, twice the space the bridge itself has to ascend.

Along with simplicity and cheapness of construction this military drawbridge fulfils the following necessary and important conditions;—1. The bridge is not greater in length than the opening intended to be spanned; 2. When the bridge spans the opening it is flush with the roadway; 3. It does not involve any alteration in the construction of the roadway at either side of the opening; 4. The force necessary to move it is so slight that any assistance from machinery is in most cases unnecessary; 5. A single action is sufficient to move it; 6. When the bridge is rolled back no part of it is exposed to damage by fire from the flanks; 7. Where gates are used in connection with the bridge, it is capable of being rolled in either direction while they remain closed; 8. When the bridge is rolled in and the gates closed, no ledge is left to assist an enemy to bridge the opening.

2556.

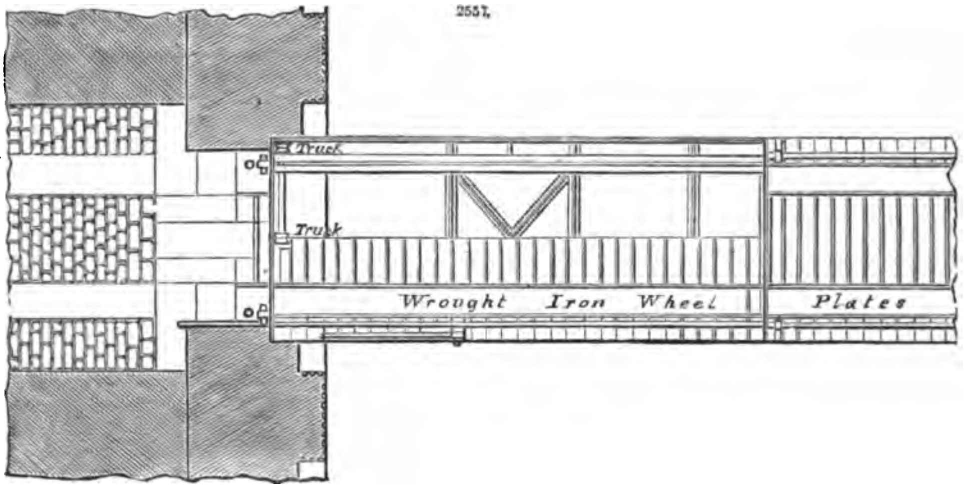


Figs. 2556 to 2558 represent an equilibrium drawbridge by J. O. Ardagh, R.E., in which no counterpoises are required; the diagram, Fig. 2559, shows how this equilibrium of the bridge in every position is attained. The platform $x\,y\,x'\,y'$ is suspended to the points Y Y by the rods Y B,

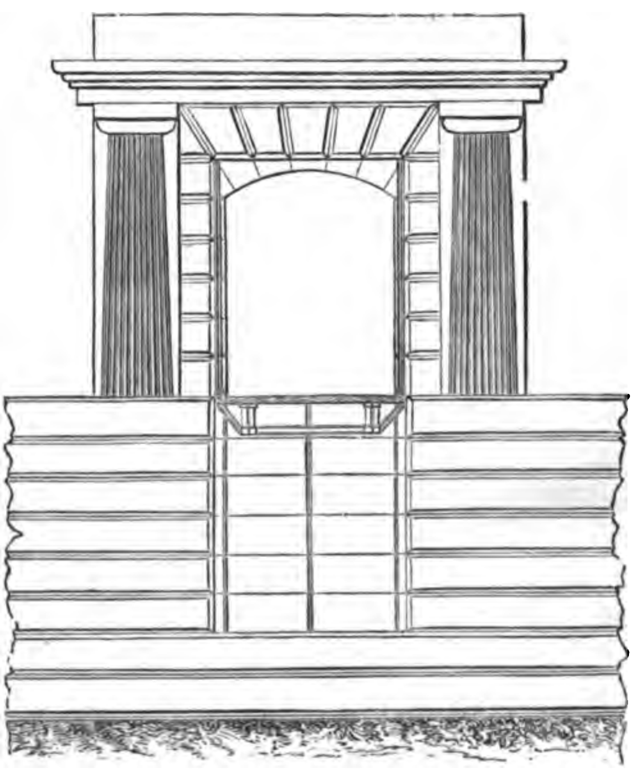
and its inner extremity $x'y'$ bears by means of flanged wheels on rails O $x'y'$ Y, curved in such a manner that the centre of gravity of the platform A shall move on the horizontal line X X', thus securing equilibrium in every position. The curve may be drawn graphically, or calculated from the following equation;—

$$x' = \sqrt{r^2 - \left(p - \frac{a y'}{a+b}\right)^2} - b\sqrt{1 - \left(\frac{y'}{a+b}\right)^2}.$$

2557.



2558.

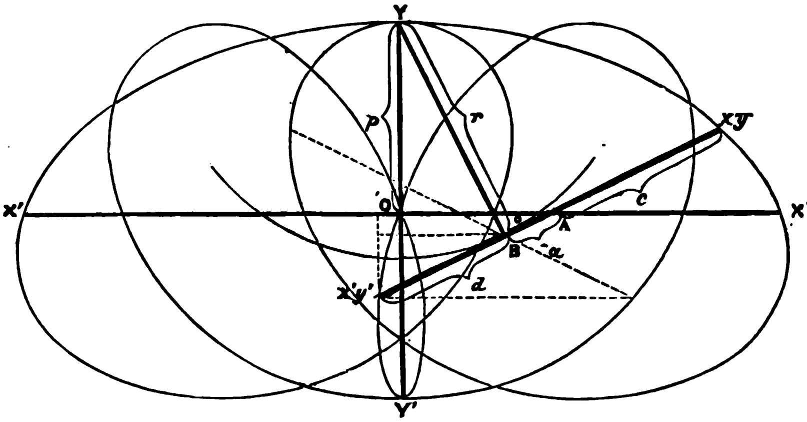


When the centre of gravity bisects the span, and the point of suspension meets the outer extremity of the bridge when raised, $a : b : (c = p) : r :: 1 : 3 : 4 : 5$.

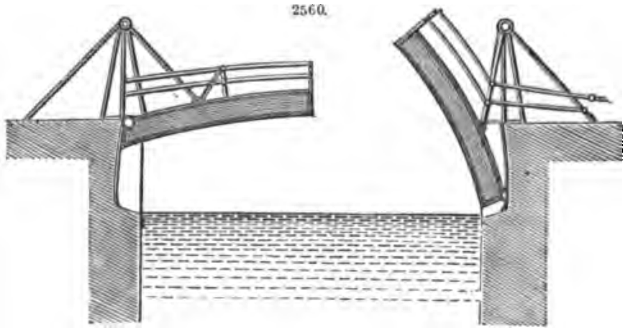
The smaller diagram, Fig. 2560, shows the mode of applying this principle to dock or canal bridges, where its compactness and lightness are advantageous.

Fig. 2561 shows an ordinary drawbridge with a very simple description of counterpoise, also invented by J. C. Ardagh, R E. The weights which balance the bridge when in a horizontal position are attached to pulleys working on slings of chain or wire-rope which constrain them to move in an elliptical curve, and preserve the equilibrium of the bridge in every position. The theoretical curve, which is a sinusoid, may be graphically described by the construction shown in dotted lines, Fig. 2561; and the foci of the ellipse, which most nearly coincides with it, will indicate the points of suspension of the sling.

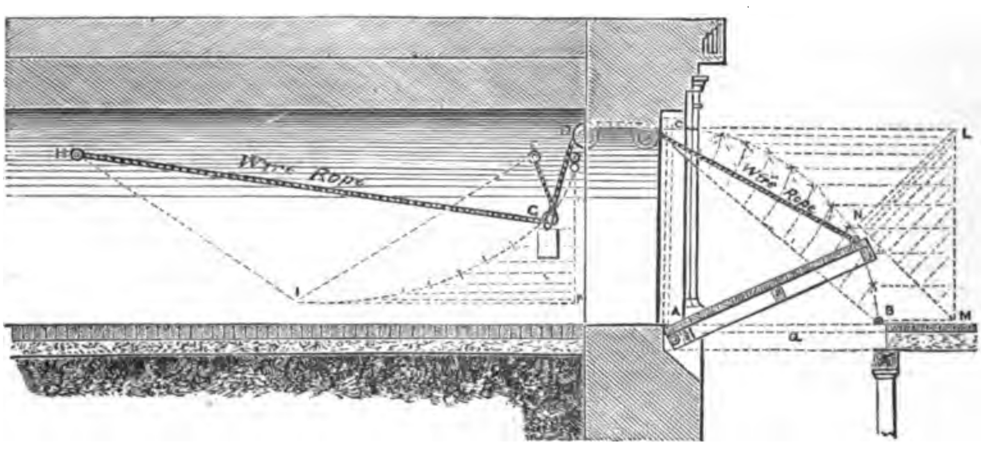
2559.



2560.



2561.



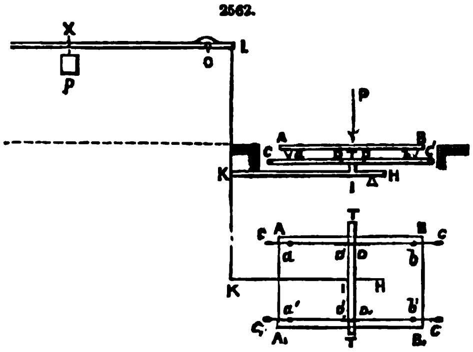
A *Weigh-bridge* is an apparatus employed for weighing conveyances. The platform A B, Fig. 2562, on to which the vehicle is drawn, rests on four feet, a, b, a_1, b_1, upon as many levers, C D, C' D', C_1 D_1, C'_1 D'_1, movable round the points C, C', C_1, C'_1, respectively; which rest by their free extremity D, D', D_1, or D'_1, upon a cross-bar T T; this bar rests at the point I upon a lever H K, movable round the point H. The extremity K of this lever is united by a vertical rod K L to the smaller arm of a balance, movable around the point O, and bearing upon its longer arm a sliding weight p. The distance O X $= x$, at which it is necessary to place the sliding weight in order to retain the beam in a horizontal position, gives the measure of the weight P of the conveyance.

The points C, C', C_1, C'_1, are equidistant from the cross-bar T; the same with the points a, b, a_1, b_1, on which are placed the four feet of the platform. It follows, first, that in every position of the apparatus the platform remains horizontal. Let us suppose, then, that the relation of C a to

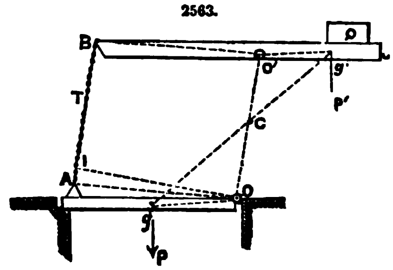
O D is that of 1 to n; if the cross-bar be lowered to an extent h, each of the points a, b, a_1, b_1, will be lowered by $\frac{h}{n}$; the platform will then remain horizontal, and will be lowered by $\frac{h}{n}$. Let us next suppose that the relation H I to H K is that of 1 to n', the point I being lowered by h, the point K will be lowered by $n'h$; and the same will take place with the point I. Then the point X will be elevated to an extent indicated by $n'h\frac{\mathrm{O\,X}}{\mathrm{O\,L}}$, or $n'h\frac{x}{l}$, calling l the distance O L. This being settled, let us apply to the system the principle of virtual velocities. The effect of the weight P is $+\frac{\mathrm{P}h}{n}$. The virtual velocity of the weight p is $-p\,.\,n'h\,.\,\frac{x}{l}$. The *virtual velocities* of the reactions of the resting points O, H, C, C', C_1, C'_1, are = 0, if we overlook the friction, as it is allowable to do when the contact is everywhere maintained by a knife-edge. Besides, the other forces which act upon the system are mutual forces, equal two and two, and of contrary signs, and whose virtual velocities disappear on computing their sum. There will then remain $\frac{\mathrm{P}h}{n} - p\,n'h\frac{x}{l} = 0$, whence $\mathrm{P} = p\,.\,n\,n'\,.\,\frac{x}{l}$.

If, for example, we have $n = n' = 10$, and $p = 1\,k$, it will result that $\mathrm{P} = 100\,k\,.\,\frac{x}{l}$.

2562.



2563.



The drawbridge represented in Fig. 2563 is composed of a platform O A, movable around a horizontal axis O by means of strong pivots, the coussinets of which are fixed on the side of the scarp. Two chains, of which only one, A B, is seen in the figure, attach the anterior portion of the platform to two plyers B O, movable round a horizontal axis O', united to one another by cross-beams and a St. Andrew's cross, and having at the back part a counterpoise Q, usually of stone. The apparatus is so arranged that if we join the points of attachment A and B of the chain to the points O and O', we obtain a parallelogram A B O' O, attached at its four angles, and which does not cease to be a parallelogram when the position of the platform is altered, seeing that its opposite sides remain equal.

Further, if g is the centre of gravity of the platform, and g' that of the system formed by the beams and their counterpoise, the weight Q and its position are disposed in such a manner as that by joining g O and g' O', we have two parallel right lines; these right lines remain parallel when the position of the platform is changed, seeing that they make equal angles with A O and B O', which remain parallel. Finally, the weight P of the platform and the weight P' of the system of the beams and their load are so regulated as that there may be equilibrium in every position of the drawbridge. To this end, let T be the tension of one of the chains, and let α be the angle which the two right lines g O and g' O' make with the horizon in any position whatever of the apparatus. The platform is a lever of the second kind, subject to the forces T, to the force P, and to the reaction R, exercised upon the axis O; taking the moments of these forces in their relation to this axis, and putting aside the friction, we shall then have $2\,\mathfrak{M}\,\mathrm{T} = \mathrm{P}\,g\,\mathrm{O}\cos.\alpha$, the character $\mathfrak{M}$ designating the momentum of the force T. The beams form a lever of the first kind, which in the same way gives

$$2\,\mathfrak{M}\,\mathrm{T} = \mathrm{P'}\,g'\,\mathrm{O'}\cos.\alpha. \qquad [2]$$

Comparing the relations [1] and [2], we obtain

$$\mathrm{P}\,g\,\mathrm{O} = \mathrm{P'}\,g'\,\mathrm{O'}, \text{ whence } \frac{\mathrm{P'}}{\mathrm{P}} = \frac{g\,\mathrm{O}}{g'\,\mathrm{O'}} \qquad [3]$$

a relation which is independent of the angle α, and which will take place in consequence in any position whatever of the drawbridge, provided that it takes place in a particular position, for example, in the position where the platform is horizontal, or where $\alpha = 0$.

Either of the relations [1] or [2] will give the tension T; it will be sufficient to make $\alpha = 0$, and to replace $\mathfrak{M}$ T by T O I, the factor O I being the perpendicular let fall from the point O, or the point O' upon A B. We shall thus have $2\,\mathrm{T\,O\,I} = \mathrm{P}\,g\,\mathrm{O}$, whence $\mathrm{T} = \frac{1}{2}\,\mathrm{P}\,\frac{g\,\mathrm{O}}{\mathrm{O\,I}}$.

The reactions upon the axes O and O' will be obtained in the same way as for the lever, that is,

by bringing in the forces T and P, or T and P'; composing these two forces by the parallelogram of forces, and taking the resultant in a contrary sense.

It will be observed that if we join $g\,g'$, the point G when this right line will meet O O' will be the centre of gravity of the system of the weights P and P'. For the triangles g O G and g' O G' being similar by reason of the parallelism of the right lines g O and g' O', we have

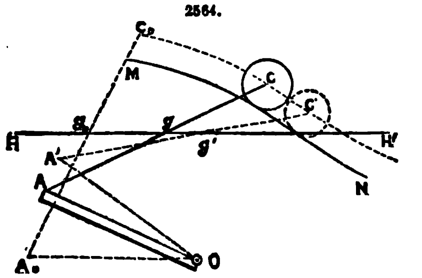
$$\frac{\mathrm{G}g}{\mathrm{G}'g} = \frac{g\mathrm{O}}{g'\mathrm{O}'} = \frac{\mathrm{P}'}{\mathrm{P}}. \qquad [4]$$

The point G remains immovable in every position of the platform, for the same triangles give

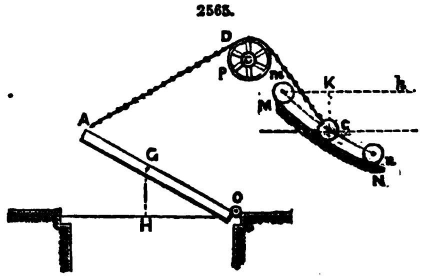
$$\frac{\mathrm{GO}}{\mathrm{GO}'} = \frac{g\mathrm{O}}{g'\mathrm{O}'}. \qquad [5]$$

In some cases another arrangement, invented by M. Delille, which is founded on a different principle, has been adopted. The chains are replaced by straight rods A C, Fig. 2564, which are attached to the extremities of the axis of a horizontal cylindrical roller, which is made to move upon curves M N. Let us suppose the weight P of the platform to be resolved into two parallel forces ½ P applied, the one at A, the other at O. Let P' be the weight of the roller, and let g be the point of application of the resultant of the forces ½ P and P', or, what amounts to the same, the centre of gravity of the system of the weights ½ P and P'. The curves M N are so described, that on moving the drawbridge, the point g describes a horizontal H H'; it follows from this that the system is an equilibrium in every position. In fact, the *virtual velocity* of the force ½ P applied at O, and of the reaction exercised on this axis, is zero, since their point of application is not displaced; the virtual velocity of the reaction exercised on the roller by the curves M N is zero, because that reaction being normal to the curves is perpendicular to the elementary line described by its point of application. There remains the virtual velocity of the forces ½ P and P' applied, one at A, and the other at C, or, which amounts to the same, the velocity of their resultant applied at g. Now this resultant is vertical, whilst the elementary line described by the point g is horizontal; its virtual velocity is then constantly zero. Thus the sum of the virtual velocities of all the forces applied to the system remains nil in any position whatever of the drawbridge, the system is then constantly in equilibrium. To trace the curves M N, Figs. 2564, 2565, we commence by determining the point g for a given position of the platform. Through this point g we draw the horizontal H H'. We then give to the platform any new position O A'; from the point A' as centre with a radius equal to A g we describe an arc intersecting H H' at a point g'; we join A' g'; and take on this right line a length A' C' equal to A C. The place of the points C' thus obtained is a curve of the 4th degree $m\,n$, which we might trace by the help of its equation, but which is more easily determined in the way just stated. This done, from each of the points C as a centre, with the radius desired to be given to the roller, we describe a circle: and then draw a curve M N tangent to all the circles thus described; this is the curve required. The curves M N are executed in iron, and form the lower border of a cavity contrived in the wall of each side of the passage, in which rest the extremities of the roller. From the manner in which these curves have been obtained, when the cylinder travels upon them, the extremities of its axis describe the curves $m\,n$, and the point g describes the horizontal H H'.

2564.



2565.



Another arrangement, contrived by Bélidor, has also been employed. The chain which suspends the platform passes over a pulley P. Fig. 2565, and is attached by its extremity to a roller C forming a counterpoise, and traversing upon a fixed curve M N. This curve is determined in the following manner. Let m be the initial position of the axis of the roller, corresponding to a horizontal position of the platform; from the point m a horizontal $m\,h$. The platform is next placed in some other position, and we measure the vertical distance G I travelled over by its centre of gravity. If P is the weight of the platform, P G I is the negative velocity of the weight upon the platform. Let p be the weight of the roller, and C K the distance from the point C to the horizontal $m\,h$; p C K will be the positive velocity of the weight upon the roller. Ignoring the frictions we should then have for the equilibrium P G I = p C K, whence we can obtain C K, and consequently the horizontal passing through the point C. On the other hand, the length of the chain being known, if we cut off from it A D, and trace the developing line described by the extremity C when the rest of the chain rolls over the pulley, starting from the point D, we shall have a curve which should contain the point C. This point will then be determined by the intersection of this curve with the horizontal drawn at the distance C K from $m\,h$. We can determine in a similar manner as many points as may be required of the curve $m\,n$ described by the centre of the roller.

The curve M N may be deduced from this by tracing the line enveloping circles described round different points of $m\,n$ as centre with the radius of the roller.

See BRIDGE, p. 791. FORTIFICATION. VIRTUAL VELOCITY. WEIGHING MACHINES.

DRAWING FRAME. FR., *Étireur*; GER., *Zieh oder Streckmaschine*; ITAL., *Stiratoio*; SPAN., *Estirador*.

See COTTON MACHINERY.

DREDGING MACHINE. FR., *Cure-môle*; *Dragueur*; GER., *Baggermaschine*; ITAL., *Cavafango*; SPAN., *Draga*.

Dredging is effected in various ways; either by drags, or scoops, or rakes, or machines. There are two sorts of hand-drags, one for raising mud, the other sand; the first consists of an iron box pierced with holes, open in front as well as at the top; to this is attached a slightly flexible handle of a length proportionate to the depth it is to work in. When this is made use of, the men in a boat make the iron box enter the sand, sustaining the handle on the shoulder, and when it is filled they raise it, and if there be any large stones they are disengaged by means of hooks; a man will raise in this manner, where the depth is not more than 4 or 5 ft., a cubic yard in the course of a day, and sometimes more.

The *drag for mud* is differently formed: it is an iron drag, to which a canvas bag is attached by passing a cord through holes made in the ring purposely to receive it; that part of the iron rim which is intended to touch the ground and enter the mud must be sufficiently strong: two men in a boat or punt are required to manœuvre it, and in the course of a day they will raise 12 to 14 cub. yds., if the depth does not exceed 6 ft. When a boat is made use of, it is first moored in such a manner that it cannot drift; such a drag allows the water to flow out of it, and retains only the solid matter.

The Louchette, or kind of spade, or a collection of them, is used for cutting or extracting turf under water without the necessity of first pumping it dry this consists of a light iron frame, which is armed all round with a cutting blade, in length about 3 ft.: the part between it and the handle is open, being formed of four horizontal rods and two vertical ones; these receive the turf after it is cut and detached, and enable the workmen, by means of a rope and windlass, to pull it up. These cutting instruments have a variety of forms given to them to adapt them to the peculiar work they may have to perform.

The *box shovel* consists of an open box fixed at the end of a long handle, usually made of iron, the cutter traverses in a groove, and is worked by another handle; by this the turf is cut and detached, and each successive piece falls into the box; as many as four turfs may be drawn up at one time. Dredging machines have been constructed in various ways, and of iron or wood, according to the nature of the service. Some machines have been arranged so that the system of chain and buckets should work through a channel in the middle of the vessel; others with one system on each side, and others with the buckets working over the extremity of the vessel. But in general the modern practice is to place the machinery towards the extremity of the vessel, to allow of the working of the ladder (which holds the buckets) freely on either side of the vessel. By this arrangement barges can be laid along both sides of the vessel, and the material raised by the machine be taken away easily. Perhaps the most popular form of machine for dredging purposes is the spoon dredger; however, we shall confine ourselves to the chain-and-bucket dredging machines.

The best-adapted boilers and engines for dredging purposes are those upon the marine principle, as in them compactness and stability are combined, and for which reasons those of that description are generally applied; in practice it is found disadvantageous to the profitable working of the machine if the engine be not of a proportionate power to the depth of water, the buckets of a suitable number, and the bucket-frame of sufficient length to lie at a proper angle. Hence the following arranged proportions are annexed as the best adapted for working at or about the various specified depths from which the material is to be raised.

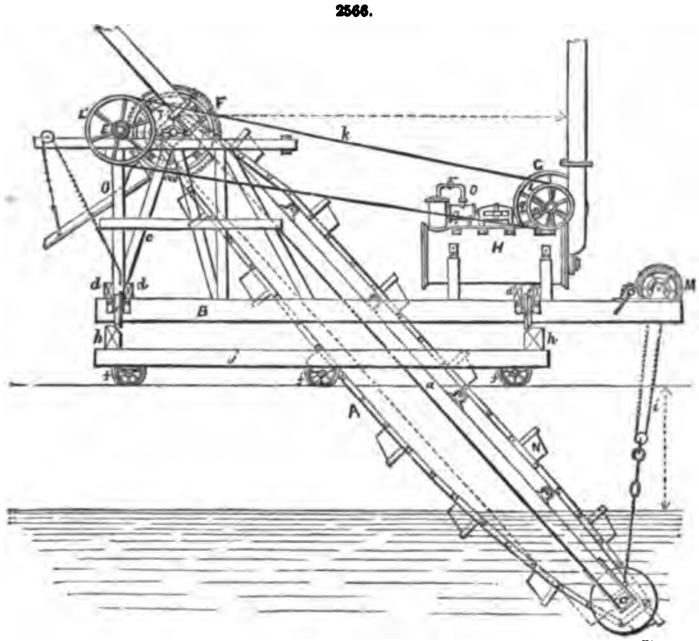
Nominal Horse-power of Engine.	Length of Bucket-frame in feet.	Number of Buckets.	Depth of Water in feet.
21	60	35	19
28	70	38	22
32	80	46	27

The boat or support requires little or no peculiarity of form otherwise than that of proper stability; it must be strong and well put together, or a constant tremulous motion is created by the action of the machinery, and the proper effect of the machine in a measure destroyed. The boat must also be of a magnitude sufficient for the receiving of the machinery, with a proper clearance for the buckets, according to the depth of water and different positions in which, on that account, they are so frequently required. In constructing the Thalie and Grison viaduct on the Paris and Lyons Railway, a bog or morass prevented the dredge-boats from entering; the engineers had the dredging apparatus removed from the boat and placed on a movable platform, shown in Figs. 2566 to 2568. The foundations having to be laid in an oozy or a miry soil, the part to be operated upon was enclosed on both sides by double rows of planks and piles, shown in Fig. 2568.

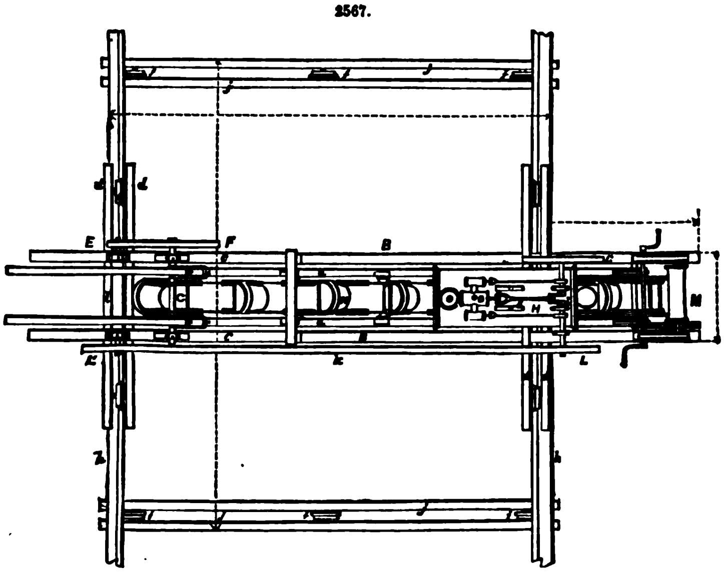
Fig. 2566 is a longitudinal section of this movable carriage-dredge when mounted and in working order; Fig. 2567 a plan; and Fig. 2568 a view of the end upon which the steam engine is placed. This dredging machine consists of a chain with buckets a, of which the axis of rotation C is mounted upon two parallel trestles c, fastened together upon two strong sleepers B, connected at each end by a series of transverse beams d, which constitute the rolling platform of the machine.

Upon two of these transverse beams *d* a small steam-engine of the locomotive class is firmly fixed, which moves the dredge. The platform B is moved upon four small wheels *e*, the axes of which are made fast to the transverse pieces *d*; the whole machine moves upon two strong bevelled sleepers *h*, placed across the principal platform, which moves upon six wheels *f*, secured by the beams *j*. So that the machine can be readily moved across the platform, and the platform and

2566.

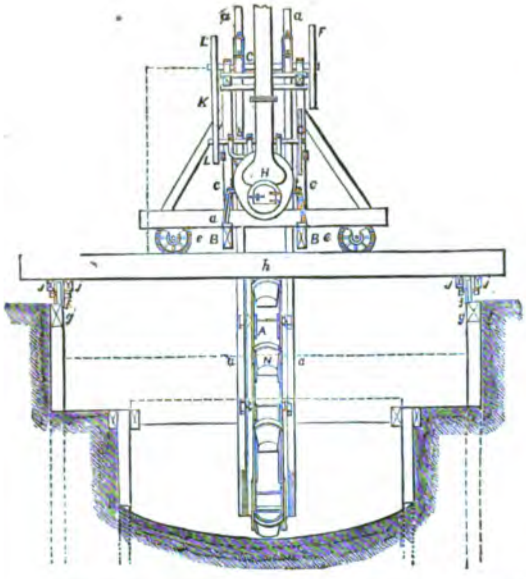


2567.



machine at any time can be rolled along two wooden rails *g*, made fast to the piles and running the whole length of the enclosure. The buckets N empty themselves upon a tray O, Fig. 2566, of which the inclination may be regulated at will; this tray deposits the material in a wheelbarrow or hand-cart. The chain of the buckets presents nothing peculiar; it is similar to that of an ordinary dredging machine. The inclination of the chain and bucket-frame is regulated by means of a winch *m*, fixed at the extremity of the frame B. This dredge is simple in construction and effective in operation; in the instance referred to it raised material from a depth of 26 ft. The

2568.



gear does not act directly, but by means of a belt K and pulley L, placed on the crank-shaft *b* of the fly-wheel *g*. On the other side there is a pulley L′, fixed upon an intermediate axle *l*, which transmits motion to the axis C of the chain of buckets by means of the pinion E and wheel F. A steam-engine of 4 horse-power was employed, making fifty-five strokes a minute, giving to the shaft of the chain of buckets nine revolutions a minute, and delivering twelve buckets of earth in the tray O during the same time; each bucket contained about six gallons. Allowing for stoppages, this machine raised from 200 to 300 cub. ft. of earth in a day, working ten hours.

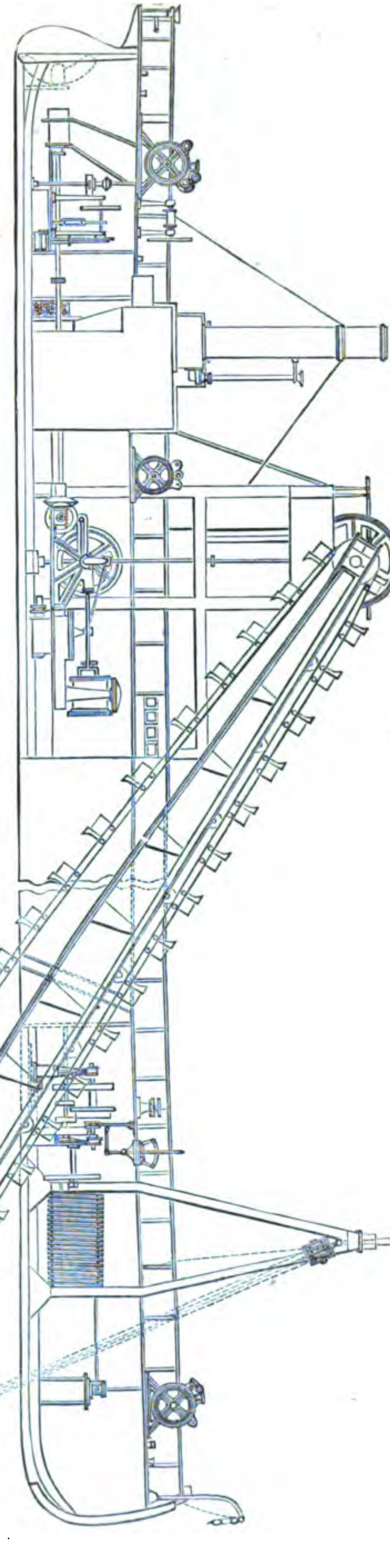
The Steam-Dredger, Figs. 2569 to 2571, built by Simons and Co., of Renfrew, for the Commissioners of the Government Works, at Carlingford Lough, Ireland. This dredger when completed steamed from the Clyde to Carlingford Lough, with her bucket-ladder in its working position. She behaved very well in a gale which she encountered when crossing the Channel, and she made on her trip an average of seven miles an hour.

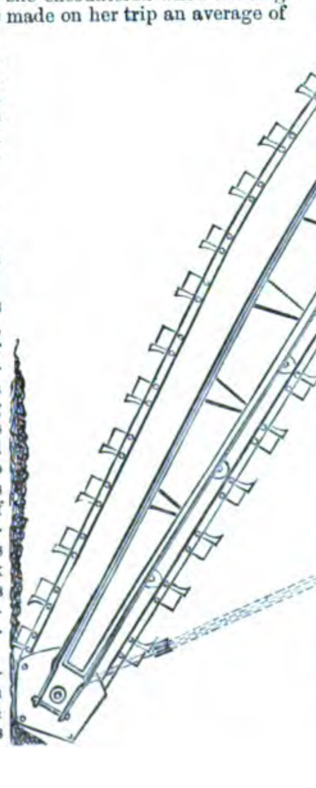
The engravings, Figs. 2569 to 2571, exhibit the general arrangement of the vessel; her principal dimensions are as follows;—

	Feet.
Length	157
Beam	27
Depth of hold ..	$9\frac{3}{4}$

The hull is strongly built of iron, and divided into four water-tight compartments, and the main framing for carrying the upper works is well braced, to stand the various strains to which the vessel is subjected. A pair of horizontal condensing marine-engines are arranged to work the dredging buckets or the twin propellers, as may be required.

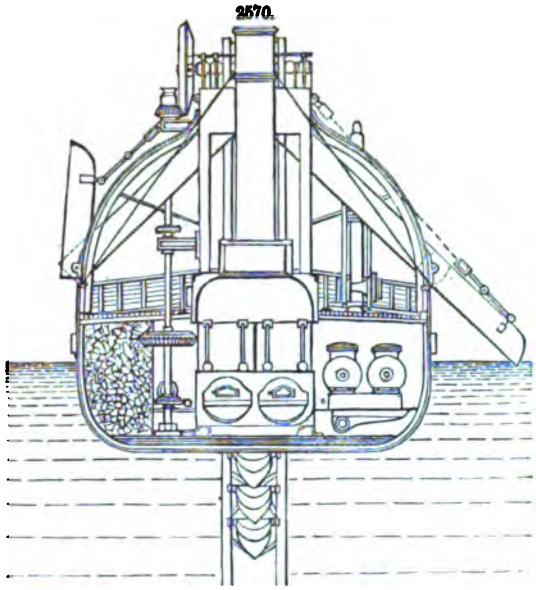
The iron bucket-ladder is 90 ft. in length, and weighs 64 tons when the buckets



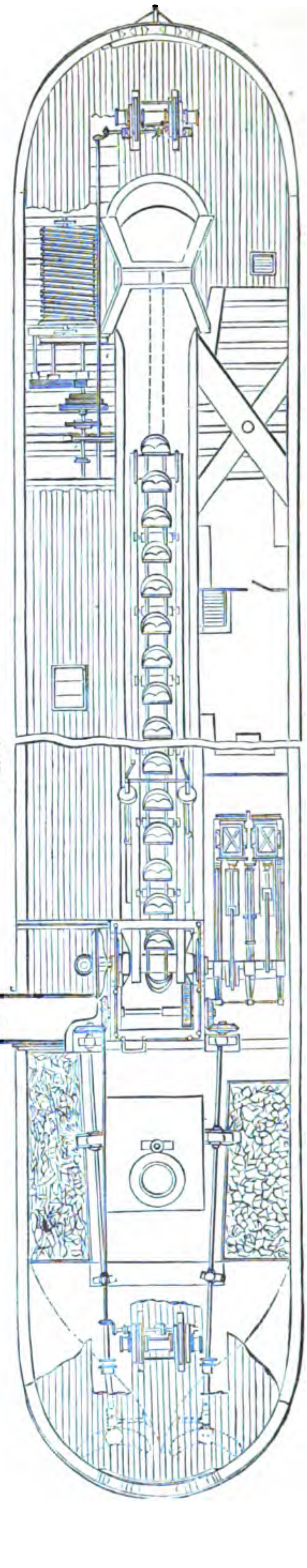


2569.

2570.



2571.



are at work. It is diagonally braced to stiffen it when at work in deep water and a rough sea. In ordinary working fourteen buckets are discharged a minute into the barges moored on either side of the dredger. The hoisting barrel, with its chain-blocks and connections for raising and lowering the ladder, weighs 15 tons, and the hand-levers are conveniently arranged for one man to work. The various motions for moving the vessel ahead, astern, and athwartship are provided with different speeds, and are driven by friction gearing.

The main gearing for working the buckets is also worked by a large bevel-wheel placed in the engine-room, and fitted with an adjustable friction centre, so as to prevent accidents in case of an excessive strain being thrown on the buckets. The upper tumbler is four-sided, and is provided with steel bars firmly fixed. The bucket backs are also of steel. The lower tumbler is five-sided, and has the end flanges formed so as to guide the buckets and prevent them from overriding when side dredging is being performed. The flanges also prevent the large boulders from getting on the tumbler bows. A four-sided lower tumbler fitted with side cutting knives and D-pieces to catch between the links has been tried, but this form of tumbler did not appear to work so well as the larger five-sided one, not clearing itself so well of the boulders.

A powerful bow *crab* winch is fixed on deck for keeping the vessel up to the cutting face, and a similar *crab* is fixed at the stern. The engine-room is supplied with the necessary indicators, gauges, counter, and telegraph from captain to engineer.

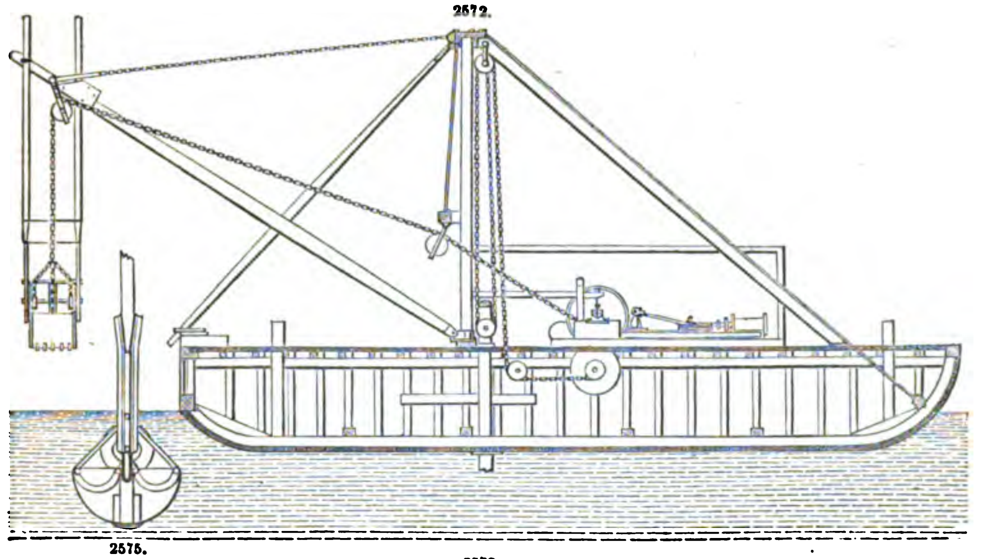
As the dredger has stormy weather to contend with, her machinery is designed so that a great portion of its weight is placed as low in the vessel as possible, so as to balance the upper parts and stiffen her. Independent donkey-engines drive the bow and stern crabs, and work bilge-pumps in connection with the various compartments of the vessel in case of a leakage. The cabin for crew is comfortably fitted with sleeping berths, lockers, and so on, for each man, a separate cabin being provided for the master and engineer.

The operation which the dredger has to carry out, namely, cutting Carlingford bar, is rather a formidable undertaking. The work has to be done in an exposed situation, the bar being in the open sea, in the British Channel, and the water is seldom smooth, whilst the tide runs with considerable force.

The bar consists principally of stiff blue clay, intermixed with a large proportion of boulder stones, many of them much larger than the buckets. These boulders are pushed forward by the lower tumbler, forming a mound in front of the cut, and occasionally some of these large stones are brought up between the buckets, resting on the links of the bucket-chain, when they are lifted out by the crane on deck. It is intended that the large boulders should be raised by divers, such stones being much too large for the buckets to lift, although each bucket has a capacity of 9 cub. ft.

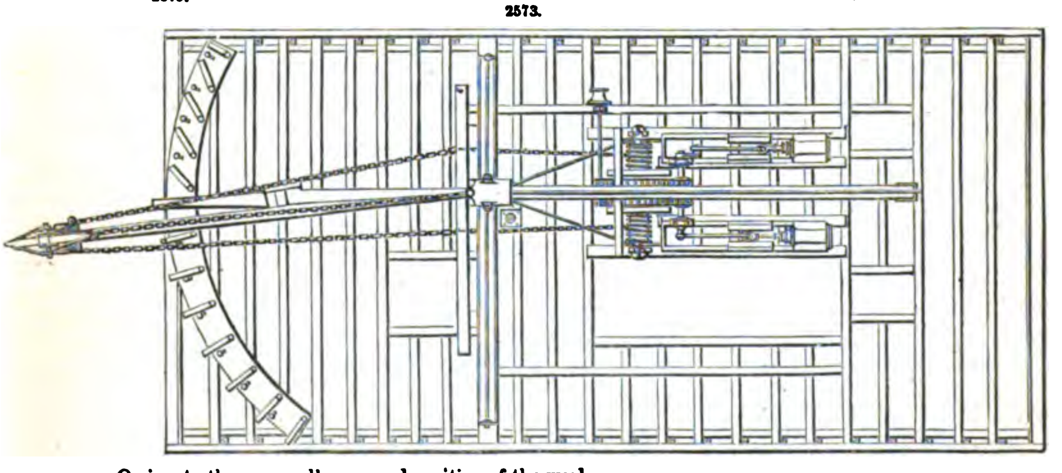
One steam-hopper barge of 200 tons burthen, and two hopper barges without power, each of 120 tons burthen, attend the machine to remove the dredged material and drop it in deep water. The larger barge can be filled in less than an hour under ordinary circumstances.

2572.



2575.

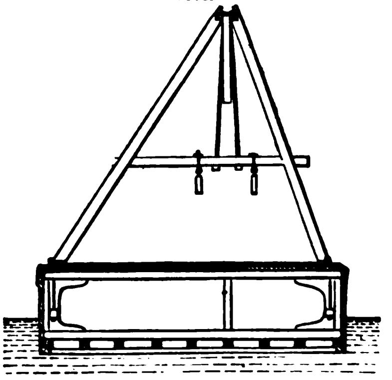
2573.



Owing to the unusually exposed position of the work, the moorings to hold the dredger when in action have to be very strong and heavy. They consist of powerful head and stern and four side anchors, all firmly secured. When the sea gets so rough as to drag the anchors and prevent dredging, the propellers are connected, the moorings let go (with buoys attached), and the dredger steams to a sheltered part of the lough until the weather moderates, and then the machine can again steam to the bar, pick up her moorings, and recommence operations.

The channel to be cut through the bar is about a mile in length by 600 ft. wide, and it is to be deepened from 8 ft. to 21 ft. at low water. Owing to the rise and fall of the tides, a part of the excavation will be done in 37 ft. water. The work has been carried on by James Barton, of Dundalk, and R. Hickson, the resident engineer.

2574.



We illustrate, by Figs. 2572 to 2575, an arrangement of dredge, designed and constructed by Morris and Cummings, of New York, and which has been used with considerable success for dredging between the slips or jetties on the Hudson river. In this machine the dredging is not performed by a chain of buckets, but by a single bucket, of somewhat peculiar

construction. The bucket consists, as will be seen by the engravings, of two parts hinged together, and provided with an arrangement by which they can be opened or closed. The two parts of the bucket are hinged at their upper inner corners, and from their outer sides tie-rods, or links, extend to a cross-bar, the ends of which work in guides, as shown. When this cross-bar is raised in the guides, the two parts of the bucket are caused to open from each other, whilst, when it is caused to descend, the two halves are forced together, and caused to securely hold any materials contained within them. The raising or lowering of the cross-bar in its guides is effected by two chains, both of which pass up over the pulleys at the end of the crane-jib and down to the hoisting machinery, each chain being led to an independent barrel. One of these chains is attached directly to the cross-bar above mentioned, whilst the other before being connected to that bar is led round a pulley placed beneath it.

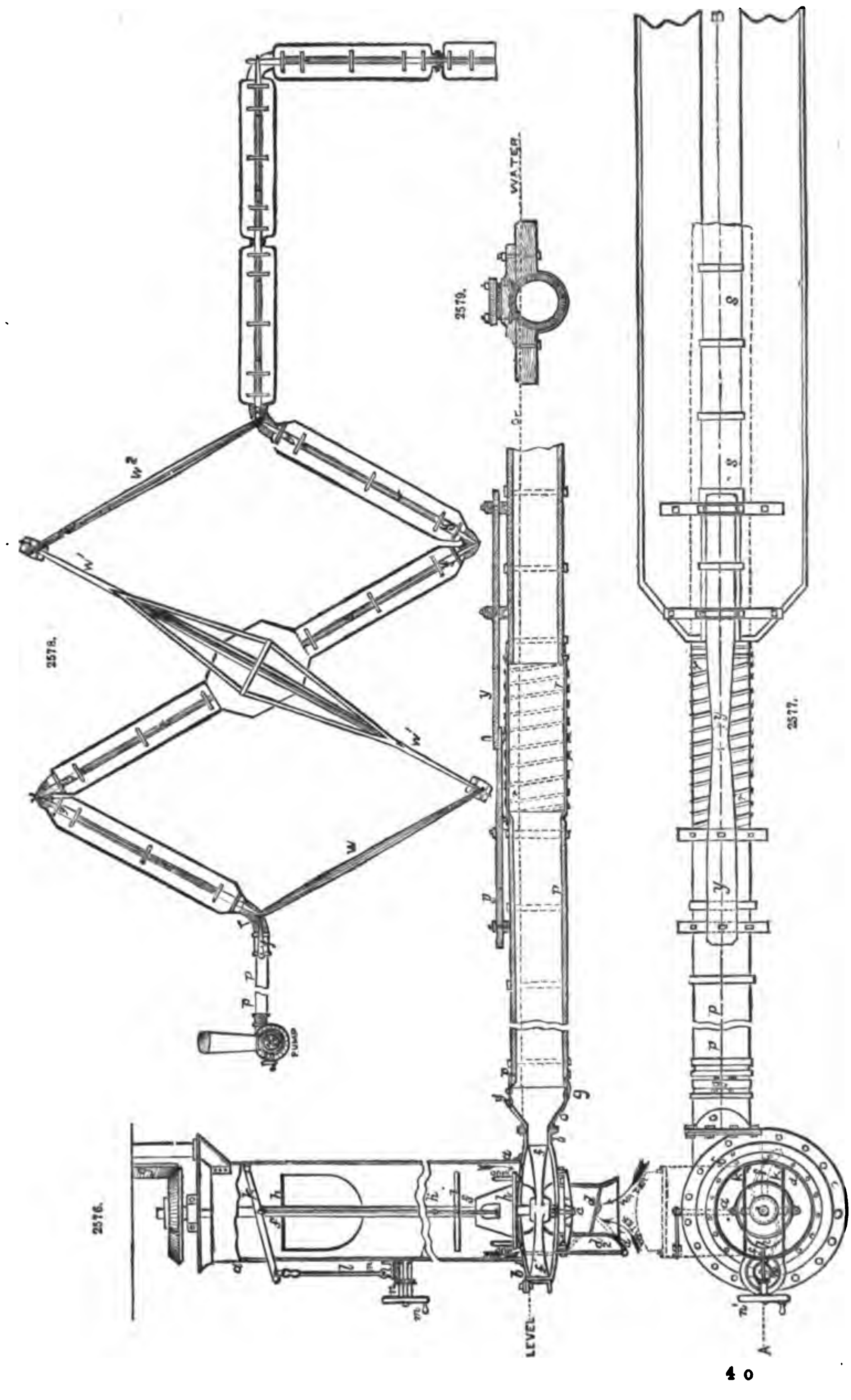
Whilst the bucket is being lowered, it is suspended by the first-mentioned chain, and the cross-bar is raised in its guides, and the two parts of the bucket kept apart. As soon as it reaches the bottom the strain is brought upon the other chain, and the cross-bar is thus hauled down in its guides, and the parts of the bucket closed before the latter is raised towards the surface. The hoisting machinery consists of a pair of horizontal engines, which by means of a friction clutch can be made to drive either chain-drum at pleasure. The bucket is guided during its descent by a pair of wooden poles attached to the guides of the cross-bar, these poles working through eyes fixed near the top of the crane-jib, as shown in the figures. After the bucket has been raised the jib is swung on one side, so that the contents of the bucket may be discharged into lighters or any other receptacle for the dredged material. The swing of the jib is regulated by a bar, which catches on one or the other of a set of stops arranged at the head of the dredger, as shown in Fig. 2573.

The engravings, Figs. 2576 to 2581, illustrate a system of transporting earth from dredgers by the employment of a stream of water, produced by means of a centrifugal pump, which has been in successful action for upwards of twelve months at the works of the Grand Canal at Amsterdam, in conjunction with ordinary dredgers. The inventor of this machine we do not know. It is carefully kept out of view, as in similar numerous cases, who invented this machine; this trick is common in many places, where the unfair sentence, "It is he who carries out an invention who deserves praise, not the original inventor," passes current.

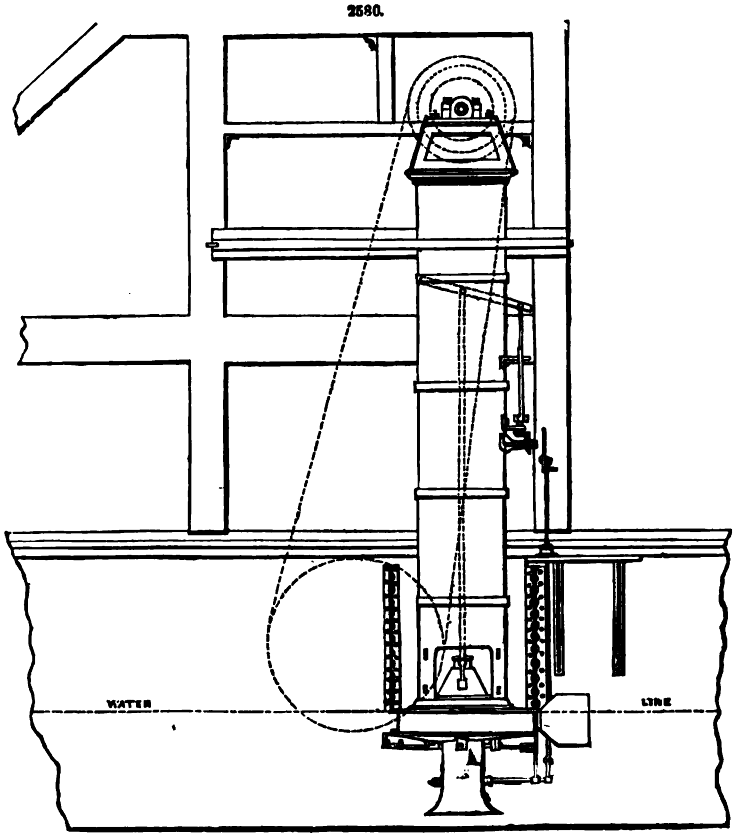
Figs. 2576 to 2579 represent different views of one arrangement of the pumping machinery and pipes, whilst Figs. 2580, 2581, show the apparatus as actually applied to the dredgers above mentioned. Fig. 2576 is a vertical section, and Fig. 2577 a plan of the machinery, *a a* being a cylinder fixed to the side of the dredger so as to receive the earth or material it is desired to convey, and *b* being the pump-case fixed at its lower end. This pump-case should be just below the level of the water from which the pump takes its supply through the water-supply passage *c*, which is adapted to an opening in the bottom of the pump-case, and is fitted with a valve *d*. This valve can be opened and closed by the lever d^1, and handle d^2; *e* is a bridge-piece fixed to the pump-casing and passing through the passage *c*, to carry the step or lower bearing of the pump-axis *f*, which has also an upper bearing at the top of the cylinder *a*; and *g g* are bevelled wheels by means of which the axis *f* is driven. The pump-blades f^1 are fixed on the axis *f*; and a^1 is an opening in the cylinder *a*, by which the earth or material is supplied to it by the dredger. This opening should be 6 ft. or more above the bottom of the cylinder. A conical valve or cover *h* is provided to regulate the passage of the earth or material from the cylinder through the opening in the top of the pump-case; and this valve has two rods h^1 h^1 fixed to it, and which pass through guides *i i* to a forked lever *k* to which they are jointed. The lever *k* extends out through the side of the cylinder, and is jointed to a rod *l*, which at its lower end is forked and holds a screw-nut *m*. This nut works on a screw, the stem of which is carried in a bearing, and has the bevelled pinion *n* upon it gearing with another similar pinion on the axis of the hand-wheel n^1, so that by turning this wheel the valve *h* can be raised and lowered; the valve is guided by the fixed guide-rods h^2. There is a tangental opening in the pump-case *b*, which receives a casting *o*, to which the pipes for conveying away the water and material are connected.

A plan of the arrangement of pipes is shown on a smaller scale by Fig. 2578. In this figure *p* is a wooden pipe made with staves like a cask, and bound together by hoops; it is connected with the casting *o* by a leather connecting tube *q*, which is clipped on to the casting and on to the pipe by metal hoops drawn together by screws. At the other end of the pipe *p*, another leather tube *r* of some length is placed, this tube forming a flexible joint, connecting it with the wooden pipe *s*. The tube *r* is kept in form by a coil of thin flat iron riveted to the leather. By similar flexible joint tubes the pipe *s* is connected with the succeeding pipes of the series, *t*, *u*, and *v v v*, which series is continued to the shore where the material is to be deposited. Each of the pipes of this series is formed with floating pieces at its sides, as shown in section, Fig. 2579, to sustain it in the water. The three tubes, *s*, *t*, and *u*, are combined together to make them more readily manageable in such a manner that although the ends of the coupled pipe can be moved to and from each other, movement is restrained by booms $w\,w^1\,w^2$. The centre and larger boom w^1 is pin-jointed at the centre to a float or saddle-piece at the centre of the pipe *t*, and the outer ends of this boom are pin-jointed to the booms *w* and w^2, the centre pins of the joints being fixed upon the floats *x x*. The other ends of the booms *w* and w^2 are jointed at the junction of the pipes *p s* and *u v* respectively. It will be seen that at each of these junctions, and wherever the flexible leather joint tubes are left free to bend, the strain is taken off the flexible tubes by means of planks *y y* fixed on each pipe-float over the pipe, and pin-jointed together at their ends. When the position of the apparatus is such that the material does not require to be conveyed over water, there may be substituted for this flexible system of floating pipes any ordinary arrangement of tubing.

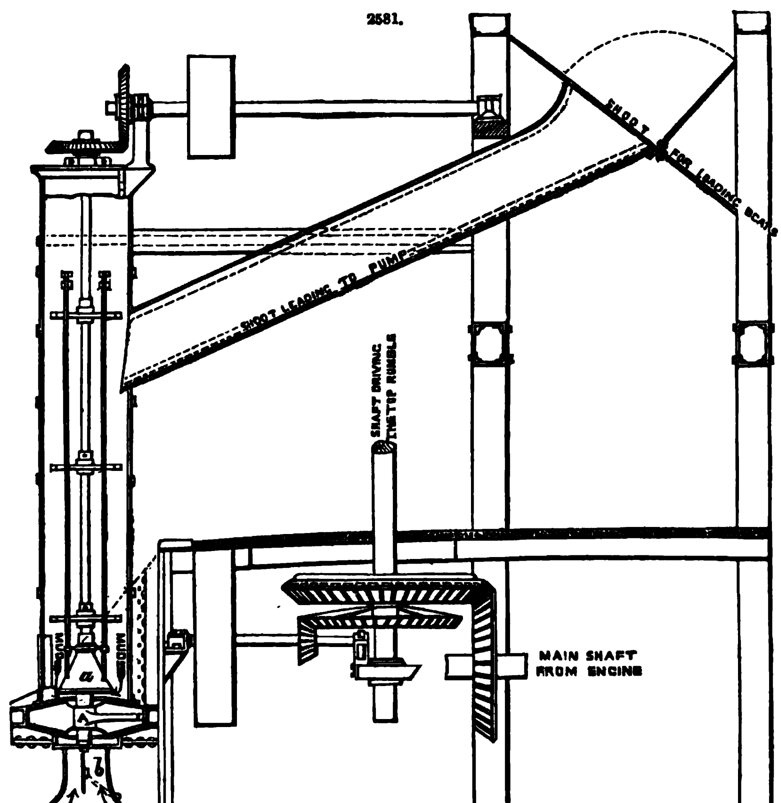
Figs. 2580, 2581, represent the apparatus as used in Holland. In this case it will be seen that a pump is bolted to the side of the dredger, and driven at the rate of 230 revolutions a minute by the same engine, by means of the bevel-gearing shown on the top. The pump, which is 3 ft. 6 in. in diameter, is fixed with the top on a level with the surface of the water, and is furnished with


2576.
2577.
2578.
2579.
WATER
LEVEL
PUMP

2580.


WATER
LINE

2581.


SHOOT LEADING TO PUMP
SHAFT DRIVING THE TOP RUMBLE
MAIN SHAFT
FROM ENGINE

two inlets protected by valves, the one on the bottom for the admission of water, and the other on the top for regulating the entry of the material to be transported. On the top of the pump is placed a cylinder or reservoir, to receive, by means of a shoot, the stuff dredged up.

The dredger is connected with the shore by means of wooden pipes, fitted with buoying pieces to enable them to float, and connected by leather joints, those immediately following the dredger being arranged on the lazy-tongs principle, to admit of its free movement in any direction. The leathern joint pipes for this portion are about 4 ft. 8 in. long, strengthened and compelled to assume a regular curve by iron spirals riveted to their outsides; but the joints for the intermediate pipes are only about 18 in. long, just enough to allow of a firm connection being made by iron hoops tightened by screws. The diameter of the pipes is 15 in.

The action is as follows;—By the revolution of the flyer A a rapid stream of water is maintained through the pipes, into which the dredged stuff is admitted through the pump by the opening on the top, and is thus rapidly mixed and carried to the delivery at the opposite end of the pipes, where the heavier materials deposit themselves in nearly level beds. An arrangement might also be made by causing the pipes to discharge into an enclosed area and running the water from the top, by which means any required thickness could be deposited.

DRILL. Fr., *Foret;* Ger., *Bohrer;* Ital., *Trapano;* Span., *Taladro.*

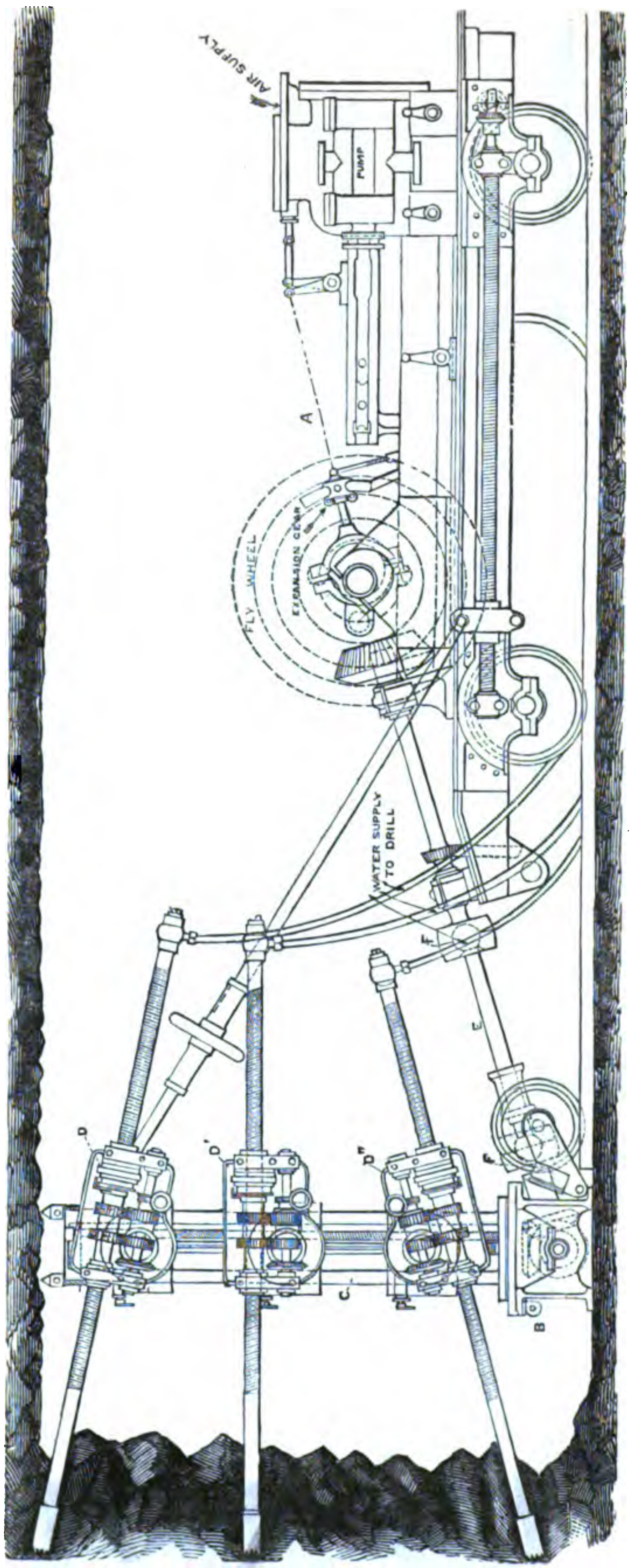
A *drill* is, strictly speaking, a boring tool that cuts with its bevelled end by revolving.

See Auger. Boring and Blasting. Hand-Tools. Machine Tools.

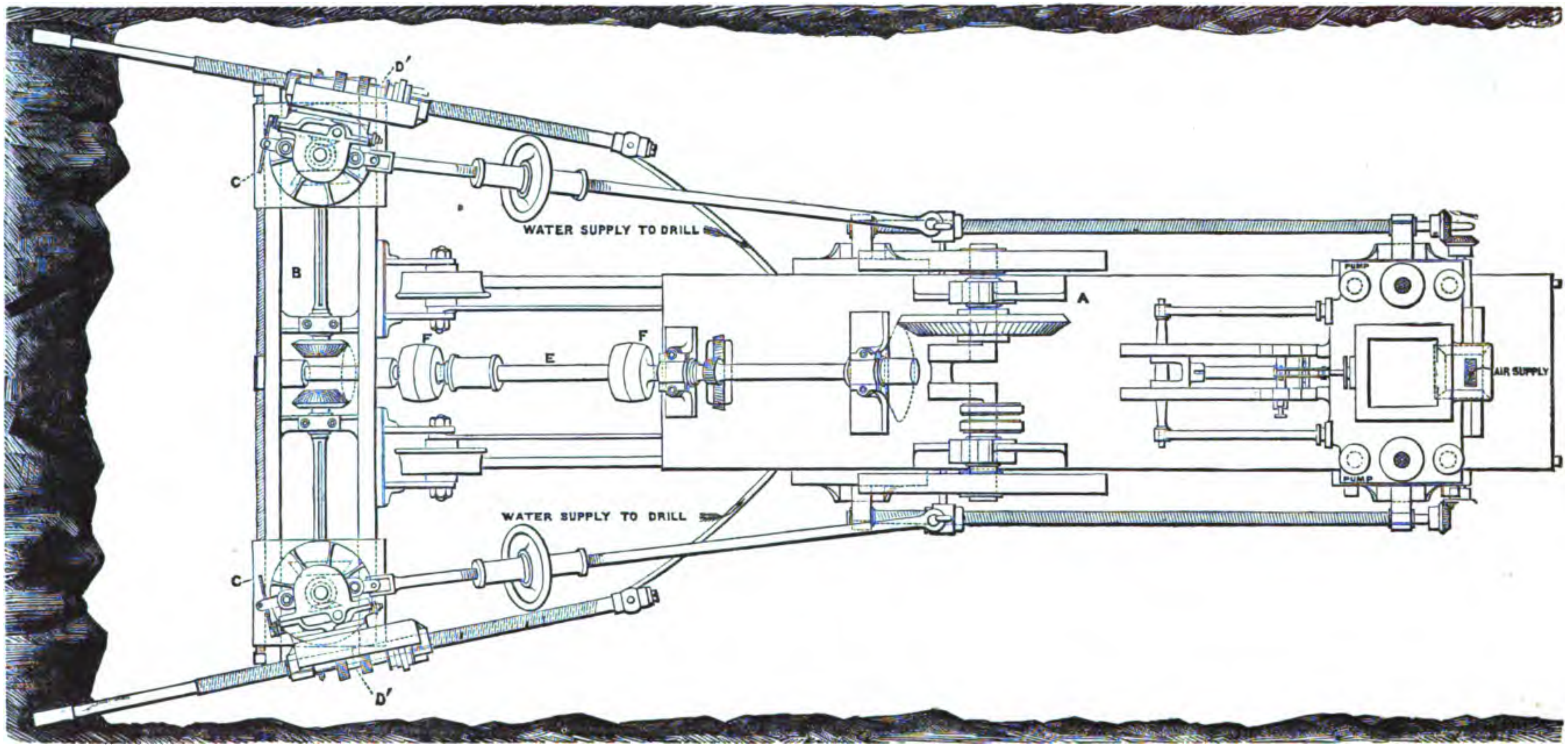
The Diamond Rock-Boring Machine.—This machine, Figs. 2582, 2583, consists of the following parts, namely;—

The driving engine or motor, A; the horizontal girder or transom, B; the two vertical standards, C, C; and the six drills, D, D, D, D, D, D, three on each standard.

2582.



2583.



D'
C
WATER SUPPLY TO DRILL
B
F
E
F
A
PUMP
AIR SUPPLY
PUMP
WATER SUPPLY TO DRILL
C
D'

The machine of which we speak was constructed by Appleby, Bros.

The motor is an engine of the ordinary description, which is worked by compressed air supplied through tubing; but, direct-acting water-pressure engines might equally well be used if found convenient.

The power is transmitted from the motor to the horizontal shaft by the oblique shaft E, which is driven by bevel-gearing from the crank-shaft of motor at one end, and drives the transom-shaft at the other end. This oblique shaft is provided with universal couplings F, F, which allow for any inequalities in the bottom of the tunnel or heading. The horizontal transom-shaft drives two vertical shafts, one in each standard, by bevel-gearing, and these vertical shafts in their turn drive the drills or borers through short horizontal shafts in the movable saddles to which the drills are fixed.

The drill consists of a strong cast-iron frame provided with suitable bearings, and in these bearings revolve the driving spindle on one centre, and the drill-bar on the other. On the driving spindle of drill are two small spur-wheels which are thrown in and out of gear by clutches; these spur-wheels gear into two corresponding wheels on the drill-bar, one of which drives the bar and the other the *nut* which gives, by means of a differential speed, the necessary feed or forward motion to the bar. This feed is set to advance at a certain fixed rate for a given pressure on the drill, when, owing to any irregularity in the hardness of the rock this pressure is augmented, the feed is automatically, either partially or entirely, thrown out of gear, the full speed being resumed as soon as softer rock is touched. The pressure can be regulated from 1 lb. up to 1000 lbs., which is the pressure required for cutting pure quartz. Each drill can be thrown out of gear independently of the other ones.

The crown which actually cuts the rock, consists of a hollow cylinder of steel, in the front end of which the carbonates, *erroneously called black diamonds*, are set in such a manner that they project both on the inside and outside of the crown, so that as it cuts its way into the rock it leaves good clearance for the drill-bar, which is also made hollow and of such a diameter internally that the core or solid cylinder of rock which is left by the crown can pass freely along the entire length of the bar.

A supply of water under slight pressure is kept constantly flowing along the inside of the drill-bar, and thence to the carbonates, where it serves the double purpose of keeping them cool and washing away the fine particles of rock produced by the cut.

Eight carbonates are set in each crown, four on the inside and four on the outside, and the wear of these carbonates is found in practice to be insignificant compared with the amount of work they do. At Croesor in Wales, where the machine is at work, crowns have cut upwards of a ½ mile of hole, in hard bustard slate, and after this the stones have retained much of their original value.

The machine illustrated by Figs. 2582, 2583, is designed to bore holes 1⅛ in. diameter × 3 ft. long.

The method of working is as follows;—The machine having been brought into position near face of rock, and there firmly fixed by means of jack-screws at top of standards, the miners proceed to drill the holes in the rock, as shown in Fig. 2582, after which the machine is run back as far as necessary on the tramway, and the holes are charged with gun-cotton or other explosive material and then fired. The centre part of the rock in the shape of a V is first brought away, and then the two sides by means of holes drilled straight in and near the extreme sides of tunnel. The holes bored are found to be perfectly cylindrical for their entire length, which is a very great advantage for blasting, as the cartridge containing the explosive material can be made the exact size of the hole, and the maximum result is thus obtained from the force of the explosion.

DRUM. Fr., *Tambour*; Ger., *Trommel*; Ital., *Tamburo*; Span., *Tambor*.

A *drum* is a short cylinder revolving on an axis, generally for the purpose of turning several small wheels, by means of straps passing around its periphery; called also *pulley*, and *rigger*, when very short in the direction of the axis, so as to have the form of a disc.

DRY-ROT. Fr., *Pourriture sèche*; Ger., *Stockung*; *Trockenfäule*; Ital., *Tarlo secco*; Span., *Carcoma*.

See Kyanizing.

DUCT-WHEELS. Fr., *Roues à couloirs*; Ger., *Filtrirräder*.

See Turbine Water-wheels.

DUSTER. Fr., *Machine à nettoyer les chiffons*; Ger., *Lumpenreinigungs Maschine*; Ital., *Macchina da batter stracci*; Span., *Máquina para limpiar trapo*.

See Paper Machinery.

DYKE. Fr., *Digue*; Ger., *Damm*; *Deich*; Ital., *Diga*, *Argine*; Span., *Malecon*.

A mound thrown up to prevent low lands from being inundated by the sea or a river is called a *dike*, or *dyke*. See Damming.

DYNAMITE. Fr., *Dynamite*; Ger., *Dynamite*; Ital., *Dinamite*; Span., *Dinamita*.

See Boring and Blasting, p. 582.

DYNAMOMETER. Fr., *Dynamomètre*; Ger., *Kraftmesser*; Ital., *Dinamometro*; Span., *Dinamómetro*.

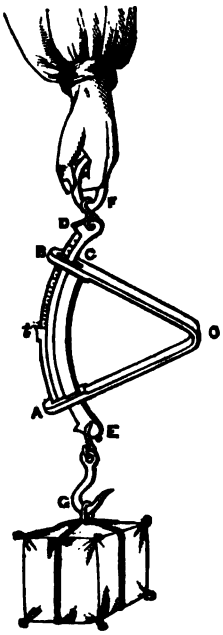
The dynamometer, from the Greek "*dynamis*," force, and "*metron*," measure, is an instrument for measuring forces, and, by extension, the work which they produce.

There are various kinds of dynamometers, but all rest upon the same principle. The chief part consist of a spring, the flexion of which may be measured; every force which, when applied to the instrument, produces the same flexion as a weight of *n* kilogrammes is said to be a force of *n* kilogrammes. Upon this principle the instrument is graduated.

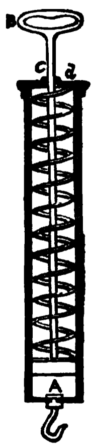
The simplest form of the dynamometer is the common weighing instrument represented in Fig. 2584. It consists of a spring A O B with two arms. At one end of the arm B O a metal circular arc is fixed, passing through the arm O A, and provided at its extremity with the ring E, to which a weight may be suspended, or any other force; a muscular effort, for instance, may be applied. At the end of the arm O A a second circular arc is fixed, capable of sliding over the first

and passing through the arm O B; this arc terminates at D in a ring which serves to hold the instrument by or to suspend it to a fixed point. This second arc is also graduated from the extremity D down to the point t where there is a kind of notch or projection, the use of which is to prevent a fracture of the spring when too great a force is applied. Suppose now the instrument suspended by the ring D to a fixed point, and a weight of 1 kilogramme attached to the ring E; the two arms of the spring will approach each other, the arc D t will pass beyond the arm O B by a certain quantity, and on this arc the point may be marked at which the arm O B stops. This operation continued with weights of 2, 3, and so on, kilogrammes, will finally complete the graduation of the instrument. To obtain fractions of a kilogramme, divide each interval into ten equal parts; this will give an approximation sufficiently near for ordinary purposes.

2584.



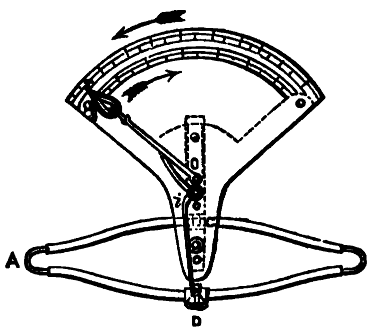
2585.



If, again, having removed the weight, we apply a force at E and the arm O B stops at the same point in the arc D t as when a weight of n kilogrammes was suspended from the ring E, we conclude that the force in question is equivalent to n kilogrammes. Thus, to measure a force in kilogrammes, we have only to apply it at E, and the number marked by the descending arm of the spring will be the value of the force.

There are other kinds of weighing instruments in which the spring is spiral, as in Fig. 2585. This spring is contained in a cylindrical metal box, to the upper part of which it is fixed in the point d; its lower end being connected with a disc A to which is attached a rod that passes through the spring along its axis and out through an orifice in the top of the box. The end of this rod is provided with a ring B by which it may be held or suspended on a fixed point. In this case the weight, or force of any kind, is applied to a hook fixed to the bottom of the box. Under the action of this force, the spiral spring is compressed in a vertical direction and the rod issues from the box. The quantity of the rod outside the box is the measure of the force. The mode of graduating this instrument is the same as in the former case.

2586.

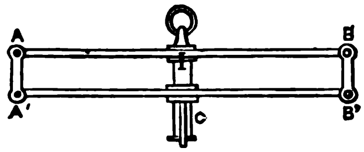


The instruments we have described are sufficiently exact for the purpose of trade to which they are applied. But to measure accurately forces greater than 100 kilogrammes, a more precise apparatus is used. This apparatus, which is known as *Regnier's dynamometer*, consists essentially of a spring A B, Fig. 2586, of two arms or branches joined at the ends. The middle C of one of the arms is fixed, and the force to be measured is applied to the middle D of the other arm, in the plane of the spring, and according to the line which would join the points C and D. The quantity by which the two arms recede from each other is indicated by the index O x, the point of which moves in a circular arc. The graduation of this arc is effected by placing the instrument in a vertical position, and then applying weights to the point D. It will be seen that the instrument has two graduated scales; one refers to the case we have supposed when the point C is fixed by means of a hand-screw placed in this point and the force is applied to the point D; the other refers to the case when the point A is fixed and the force applied to the point B. In this latter case the force is measured by the receding o. the points A and B, which implies the approach of the points C and D; and this approach is marked by a second point y of the index, which moves in a second circular arc concentric with the first. When the points C and D approach each other, a rod fixed to the point D turns a crooked lever to which it is jointed in i; and the long arm of this lever moves the index in the direction of the lower arrow; but when the points C and D recede from each other, the lever turns in the opposite direction, and the index resting by its weight against the lever, moves in the direction of the upper arrow. The second mode of employing the instrument, by fixing the point A and applying the force at B, serves to measure considerable forces, the muscular force of a horse, for example.

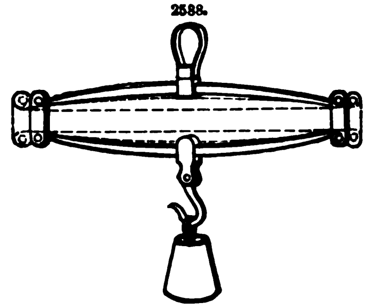
Poncelet is the inventor of a much more simple dynamometer, which was made use of by Morin in his researches in connection with the subject of Friction. It consists, as shown in Fig. 2587, of two equal and parallel strips of steel A B, A′ B′, jointed at their extremities. The middle I of one of these is fixed and the force applied to a hook C placed for this purpose on the other. The force is measured by the quantity by which the middles recede from each other, this quantity being indicated by the strips themselves on a divided rule fixed upon one of them. The advantage of

this arrangement consists in the fact that, if the force does not exceed a certain limit, the variation of the distance between the two middles, that is, the excess of the distance observed over the primitive distance corresponding to the natural state, is proportional to the force that causes it; so that knowing this excess for a determinate force, by measuring the distance corresponding to a given force we may deduce the measure of it by a simple proportion. If the forces to be measured are great, the parabolic form may be given to the springs, as shown in Fig. 2588. The flexions obtained are, in this case, the double of those which would be obtained with springs offering the same resistance, but having a uniform thickness, a fact which increases the precision of the instrument. It was found from experiments made by Morin that the flexions remain proportional to the forces exerted so long as these flexions do not exceed $\frac{1}{10}$ of the length of the springs, reckoned from the joints.

2587.



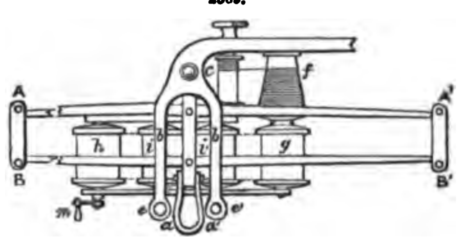
2588.



Dynamometers are employed also to measure the work done by these forces; they are then called style or tell-tale dynamometers, according to the principle of their construction, and they are arranged in two different ways, according as the motion to which they are applied is one of translation or of rotation, such, for example, as the motion of a carriage or of the driving axle of an engine. We will first consider a motion of translation, in which case the instrument is called a *traction dynamometer*.

Two equal springs A A′, B B′, Fig. 2589, of about $0^{m}\cdot68$ in length, level on their inner surface, and parabolic on their outer surface, are jointed together at their ends and held in the middle by two catches. The catch of the spring A A′ is fixed to the vehicle on which the experiment is to be made, and the other on B B′ is provided with a ring *a a′* to which the motive power is applied. The part in the figure marked *b b′* is intended to prevent injury to the springs from overstraining; it is connected with a similar piece on the other side of the springs by the bolts *e e′*, against which the front spring strikes.

2589.



To the front catch is fixed a pencil, and below the pencil a roll of paper is arranged which moves with a motion proportional to that of the vehicle, but in a perpendicular direction. To obtain this motion, an endless band is passed over the nave of one of the front wheels, and the band made to turn a small pulley-wheel, to the axle of which an endless screw is attached; by this means the little cylinder *c* is made to revolve. A cord passing round this cylinder transmits the motion to a conical drum *f*, upon the axle of which the cylinder *g* is fixed; this cylinder receives the paper, which is first rolled round the cylinder *h*. The paper is held in contact with the pencil by the two intermediate cylinders *i* and *i′*. A crank handle *m* serves to roll the paper upon the cylinder *h*. The use of the conical drum *f* will be obvious. If the motion of the vehicle were transmitted directly from the little cylinder *c* to the receiving cylinder *g*, as the paper which is rolled on it gradually increases its diameter, the motion of the vehicle remaining uniform, that of the paper would be accelerated. This inconvenience is avoided by interposing the drum *f*, whose diameters are so calculated that its rotary motion is retarded as the paper is rolled upon *g*, and consequently the motion of the paper remains uniform.

A second pencil, fixed to one of the guard-pieces *b b′*, traces upon the paper a straight line, which serves as a term of comparison in computing the distance of the springs apart, marked by the curve which the pencil affixed to the front catch traces. The fixed pencil is arranged so that the straight line traced by it may correspond with the natural state of the springs, that is, to no effort on the part of the motor. It follows from this that the ordinates of the curve, reckoned from this straight line, are proportional to the forces exerted; besides this, the abscissæ parallel to this straight line, or the tracks described by the paper, are proportional to the roads passed over by the vehicle; consequently, the work effected by the motor is proportional to the area of the curve traced by the moving pencil, and comprised between this curve and the right line traced by the fixed pencil.

This area may be computed by the ordinary methods of quadrature, or by means of a *planimeter*. But Morin has pointed out a much simpler method. The paper used for this purpose is machine made, and of great homogeneity; we may, therefore, admit that its weight is proportional to its superficial extent. Hence, if we cut the paper along the curve and the straight line, and weigh the band thus obtained, knowing the weight of a superficies of the same paper, the whole rectangular band, for instance, whose dimensions are known, we may deduce the area by a simple proportion.

We know to what force a given distance between the springs, or any ordinate of the curve, corresponds. We know also, from the transmission of the motion, the distance or track described by

the paper which the vehicle is advancing by a given quantity, 1 mètre, for example; we, therefore, easily deduce from the area found the number of kilogrammètres representing the work effected. Let λ be the distance between the springs, produced by a force of 1 kilogramme, and y the distance produced by a force F; we shall have $F : 1^k = y : \lambda$, whence $F = \frac{y}{\lambda}$, in kilogrammes.

Let ϵ be the track described by the band of paper for 1 mètre of distance traversed by the vehicle, and x the track described by the paper for a distance of e mètres; we shall have

$$x : \epsilon = e : 1^m, \quad \text{whence } e = \frac{x}{\epsilon}, \quad \text{and } d e = \frac{d x}{\epsilon}.$$

Now the work T, effected by the force F, is expressed by

$$T = \int F\, d e, \quad \text{or } T = \int \frac{y}{\lambda} \cdot \frac{d x}{\epsilon} = \frac{1}{\lambda \epsilon} \int y\, d x;$$

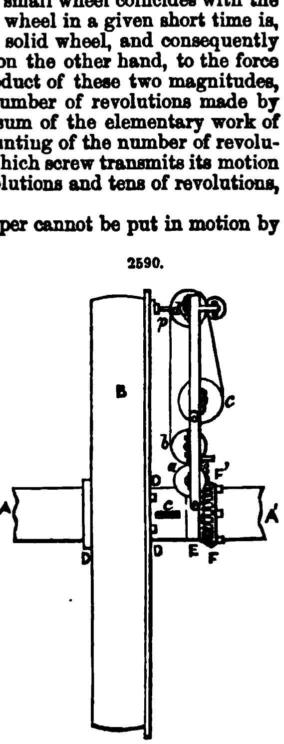
but the area of A of the curve traced by the moving pencil is expressed by $A = \int y\, d x$ between the same limits. We get, therefore, $T = \frac{A}{\lambda \epsilon}$, and this value will be expressed in kilogrammètres. Suppose, for example, that the area found is 0·75 square mètres. Let $\lambda = 0{\cdot}000125$, and $\epsilon = 0^m{\cdot}018$; we conclude $T = \frac{0{\cdot}75}{0{\cdot}000125 \times 0{\cdot}018} = 333333$ kilogrammètres.

With bands of paper 16 or 18 mètres in length, the experiment may be continued over a distance of more than a kilomètre.

When it is required to continue the experiment over a greater length of road, this kind of dynamometer is not sufficient, and the tell-tale dynamometer is substituted for it. On the hinder catch is fixed a vertical rotating axis having on its lower end a pulley-wheel which receives the motion of one of the front wheels by means of an endless cord. On the same axis is fixed a horizontal solid wheel which revolves with the pulley-wheel. To the front catch is affixed a horizontal rotating axis, bearing at its extremity a small wheel, the circumference of which is in contact with the horizontal solid wheel, and which, consequently, receives the motion of the latter—a motion which becomes more rapid as the small wheel recedes from the centre of the other, and which, therefore, is proportional to the force that separates the springs, since the small wheel coincides with the centre when at rest. The number of revolutions made by the small wheel in a given short time is, therefore, proportional, on the one hand, to the rotary speed of the solid wheel, and consequently to the elementary track or distance described by the vehicle, and, on the other hand, to the force exerted upon the dynamometer. It is thus proportional to the product of these two magnitudes, that is, to the elementary work effected by the force. The total number of revolutions made by the small wheel during the experiment represents, therefore, the sum of the elementary work of the force, that is, the total work of this force. To facilitate the counting of the number of revolutions, an endless screw is arranged on the axle of the small wheel, which screw transmits its motion to indices moving on divided limbs, and marking upon one the revolutions and tens of revolutions, and on the other the hundreds and thousands.

In making experiments in towing vessels, when the band of paper cannot be put in motion by the vehicle itself, an arrangement of clockwork is employed, which gives it a sensibly uniform motion.

2590.



The curve traced by the pencil does not in this case give the work of the force, but its *impulse*, or $\int F\, d t$; and, by dividing it by the total duration of the experiment, we obtain the mean value of the force exerted.

If it be required, in this case, to compute the work, it may be accomplished by placing marks along the shore, and making a stroke on the paper every time the vessel passes one of these marks. The strokes thus made divide the curve into portions, the mean value of the force of each of which may be computed. Multiplying this by the distance between the two corresponding marks, we obtain an approximative value of the work which applies to the interval between these marks. The same process is continued for the other intervals, and the sum of the work so found is the total amount of work; but this method gives only a rough approximation.

Let us now suppose the case of determining the value of work in a rotary motion, in which case the dynamometer is called a rotation dynamometer. The motion is transmitted by means of a belt to an auxiliary axle A A′, upon which is fixed by slight friction a wheel B of about $0^m{\cdot}89$ in diameter, Fig. 2590, intended to transmit, by means of a second belt, the motion of the auxiliary axle to the other parts of the machine, and to overcome the resistances to which it is subject. The axle A A′ cannot carry round the wheel B, because it is not solid with it; but a spring, the end c of which is shown in the figure, is fixed into this axle in the direction of a radius; and in the motion of A A′ its end comes in contact with a piece D D′, fixed to the wheel, and carries the latter round after having undergone a flexion proportional to the force to be transmitted.

Upon the axle A A′ is fixed a framework, one side, E E′, of which is shown in the figure; this framework, which moves with the axle, carries a system of cylinders analogous to that we described when speaking of the translation dynamometer, and which puts in motion a strip of paper pressed

upon by a pencil p fixed to the wheel. The paper receives a motion proportional to that of the axle in the following manner. This axle is embraced by a collar F F′, which may be made, fixed in space; this collar forms a conical wheel which gears into a conical pinion partly shown in the figure; the axis of this pinion is adapted to the axle A A′, and is provided with an endless screw which gears into a cylindrical pinion fixed upon the axle of the little cylinder a. Upon this cylinder is wound the thread which turns the conical drum b; upon the axle of this drum is fixed a cylinder around which is wound the band of paper, unwound from the cylinder c by passing over the cylinder d. It will be seen that the conical pinion being carried round with the axle A A′, and the collar F F′ being fixed in space, the pinion is forced to assume a rotary motion about its own axis, and it communicates this motion to the band of paper. If the pencil p were solid with the axle A A′, it would trace upon this band a straight line, which, according to the arrangement adopted, would be the middle of the rectangle it forms; but as the pencil is fixed to the wheel, and consequently follows the flexion of the spring, it traces a curve, the ordinates of which, with reference to this middle line, represent the flexions of the spring, that is, the forces transmitted; whilst the abscissæ, reckoned according to this same middle line, that is, the distances run through by the band of paper, represent the distances described by the point of application of this force. The work effected is, therefore, again represented by the area of the curve traced upon the paper.

It must be remarked that the axis of the conical pinion is in a plane perpendicular to that of the axle A A′, but that these two axes never meet.

We have here an example of helicoid gearing, which might be replaced by a hyperboloid gearing.

The spring is balanced by a counterpoise on the opposite side of the axle. And to avoid the risk of breaking the spring the displacing of the wheel is limited.

As in the case of the traction dynamometer, the tell-tale wheel may be substituted for the band of paper and the style. The solid wheel, perpendicular to the axle A A′, is put in motion by a toothed wheel turned by the endless screw upon the axle of the conical pinion. The little tell-tale wheel is affixed to the wheel B. When at rest, the little wheel occupies the centre of the solid wheel; but when in motion, it recedes from it by quantities proportional to the flexions of the spring; so that the number of revolutions that it makes in a given time is again proportional to the product of the force exerted by the distance run through, that is, to the work effected. With this apparatus, the experiment may be continued for a day, a week, or even a month, if the various parts are properly proportioned.

The principle of the instruments we have described is due to M. Poncelet. The Bentall and Saurines dynamometer are founded on the same principle.

The former of these instruments is used to compute the work of ploughs. Its chief part is a spiral spring carried upon wheels and fixed by one end to the plough and by the other to the swing-bar to which the power is applied. The fore end of the spring is connected with the horizontal axle of a small wheel which rests upon a horizontal solid wheel; the latter receives a rotary motion about a vertical axis, which is proportional to that of the vehicle; and the small wheel recedes from the centre by a quantity proportional to the flexion of the spring. Whence it follows, that the number of revolutions made in a given time is proportional at once to the force exerted and to the distance traversed, and consequently to the work done by the motor. Unfortunately this instrument is liable to be thrown out of order by the inequalities of the soil, and it does not always give exact results.

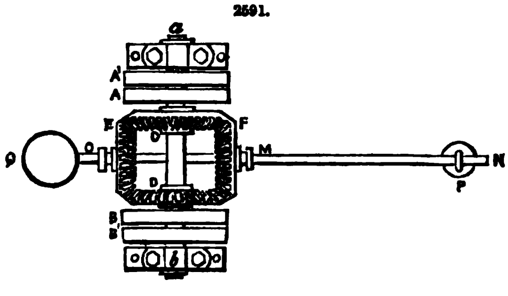
The dynamometer introduced into the French navy by M. Saurines serves to compute the work consumed by the helicoid screw-propellers. In screw vessels, the axle of the cranks of the steam-engines runs into the axle of the screw, to which it is fixed. Saurines' dynamometer is placed at the point of interruption of those two axles. To the end of the crank-axle are fixed two equal arms diametrically opposed; and to the corresponding end of the screw-axle are fixed two similar arms, but placed at right angles with the first two. The ends of the latter are connected with the ends of the other two by flat springs, thinner at the middle than at the ends, and presenting a natural curve which has a tendency to diminish under the influence of a longitudinal tractive force. It will be seen that the crank-axle cannot turn the screw-axle except through the medium of these springs which yield by a quantity proportional to the force exerted. It is, however, not this deformation that is measured directly. The middles of the opposite springs are connected by steel bars; when the springs by yielding tend to become straight, their middles approach the axis of rotation, and force the steel bars to bend. It is this flexion that is used to compute the work transmitted. For this purpose, a piece of paper is placed on a fixed cylinder having the same axis as the revolving axles; and perpendicularly to the surface of this cylinder are placed two pencils, carried round by the general rotary motion. The first, which is fixed with respect to the axle of the cranks, traces on the paper the line *zero*, the one corresponding to no force transmitted. The second, fixed to the steel bars, which tend to move it in the direction of, and along the length of the axle, but held at the same time by a spring, traces upon the cylinder a curve which deviates from the line *zero* by quantities proportional to the force transmitted. The area comprised between this curve and the line zero is, therefore, proportional to the work effected. This arrangement, invented by M. Saurines, enables us to compute easily the large amount of work transmitted to the screw of powerful vessels, often amounting to more than 2000 horse-power. To obtain correct results, however, the engines must not exert too variable a force.

Bourdon has lately invented a rotation dynamometer that is quite new in its arrangement. It consists of two cogged wheels of helicoidal gearing, equal and with parallel axes, which tooth into each other. One of them receives the motion of the motor by means of a belt; the other transmits in like manner to the operator the motion which it has received from the first. But its axis may be displaced in the longitudinal direction, by resting at one of its ends, against a spring. The pressure which this second wheel receives from the first has a component parallel to the axis which is proportional to it; this component produces a slight displacement of the axis which causes the

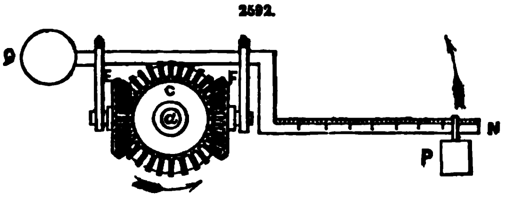
spring to yield by a certain quantity. This flexion is transmitted to an index which moves on a divided circular arc. By means of this arrangement very considerable forces may be measured by employing only thin and very flexible springs. Knowing besides the distance described by the point of application of the motive force, we are in possession of all the elements necessary to compute the work transmitted.

It remains for us to say a few words of the instrument known as the *American dynamometer*, invented by White, which is founded on a principle quite different from those of the preceding. This dynamometer, which serves to measure the work on engines, offers an application of the Roman balance. It is represented in Figs. 2591, 2592. Upon a horizontal axis $a\,b$ are mounted; 1, a pulley A which receives the motion from the motor, by means of a belt; 2, a loose pulley A', equal to the first, upon which the belt is passed when it is required to stop the apparatus; 3, a pulley B which transmits the motion and is designed to overcome the resistances; 4, a loose pulley equal to B, B'; 5, two bevelled gear-wheels C and D, both of which tooth into two other similar wheels equal to each other E and F. The axis of each of these is connected with the beam of a kind of Roman balance O M N, held in equilibrio by a counterpoise Q. On the long arm M N of this beam slides a running weight P, and this arm is divided into equal parts.

2591.



2592.



Suppose that the motion of the driving pulley A takes place in the direction of the first arrow. If the belt be thrown off on the side of the resistance, the beam has a tendency to be drawn in the direction of the second arrow, and the dynamic equilibrium can be restored only by hooking the P to the ring and by giving it a proper position on the beam, whence we easily deduce the momentum of the force P, equal to that of the resistance, and consequently the resistance itself; since it acts tangentially to the pulley B, the radius of which is known. A tell-tale put in motion by the revolving axle by means of an endless screw gives the number of revolutions and fraction of a revolution which the axle makes in a given time. Thus we have the two elements of the work to be measured, and consequently this work itself.

To prevent the oscillations of the beam during the experiment, or at least to reduce the magnitude of them, its extremity is attached to a piston which moves within a cylinder, the air in the cylinder being compressed by the motion of the piston. See ACCELERATION. ANGULAR MOTION, or VELOCITY. BALANCE. BELTS. BRAKE.

DYNAMOMETER CAR. FR., *Wagon Dynamomètre*; GER., *Dynamometer-Wagen*; ITAL., *Dinamometro di trazione*; SPAN., *Wagon dinamométrico.*

This ingenious and useful machine, shown in Figs. 2593 to 2597, was employed by MM. Vuillemin, Guebhard, and Dieudonné, in making their useful and extensive experiments on the resistance of railway trains, and on the power of locomotive engines. The results obtained by this accurate and complete machine, with respect to the different elements involved in the motion of carriages and engines on railways, on account of their practical importance, we give at full length.

To determine the resistance of a single carriage or of an engine to traction, we have had recourse to two methods.

First Method.—This consisted in driving the engine or the carriage at a certain velocity, and then suddenly leaving it to itself till it stopped. The distance was then measured from the point at which the retardation of the motion began to the point where it became nul.

Let m be the mass of the vehicle;
v_0 its initial velocity (in mètres a second);
s the space traversed (in mètres);
x the mean resistance during the traversing of this space (in kilogrammes).

If the line is level, we shall have the following equation;—

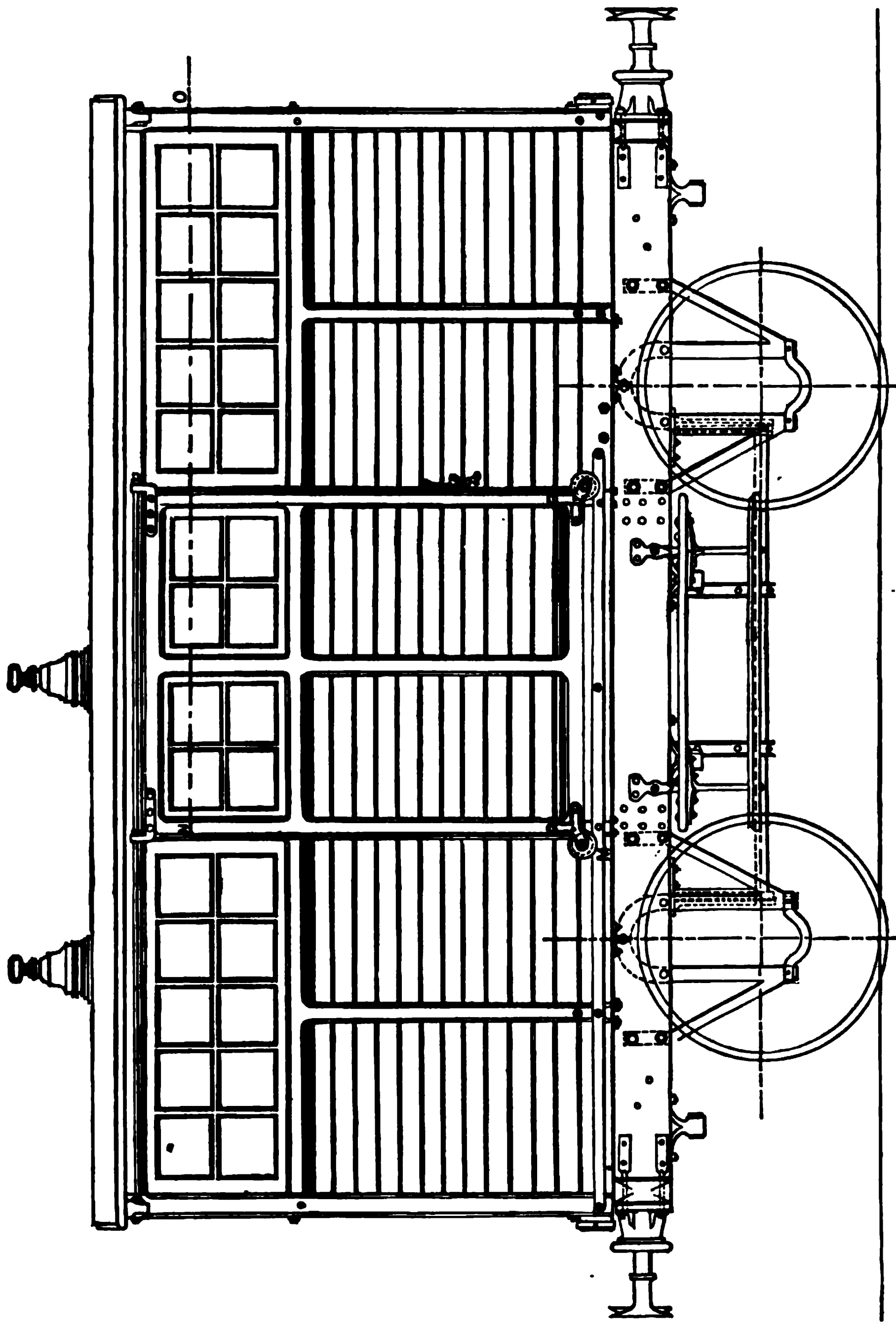
$$\frac{1}{2}\, m\, v_0^2 = x \times s. \qquad [\alpha]$$

The mean value of the resistance x may be determined.

The equation [α] must be completed by a term taking into account the rotatory force of the wheels. This force tends to impel the vehicle forwards. We shall give later the details of the calculation relative to this correction, and it will be seen that, for a carriage, a term $25\, v_0^2$ must be added to the first member of the equation. We shall then have

$$\left(\frac{1}{2}\, m + 25\right) v_0^2 = x \times s. \qquad [\beta]$$

This method may be employed to determine the resistance for a given velocity, or the tractive power which must be exerted upon the vehicle to maintain this velocity. Suppose that, during the time of retardation, a certain number of points have been marked for the time and the space. We may then construct the curve of the spaces traversed as a function of the time, $s = f(t)$. If

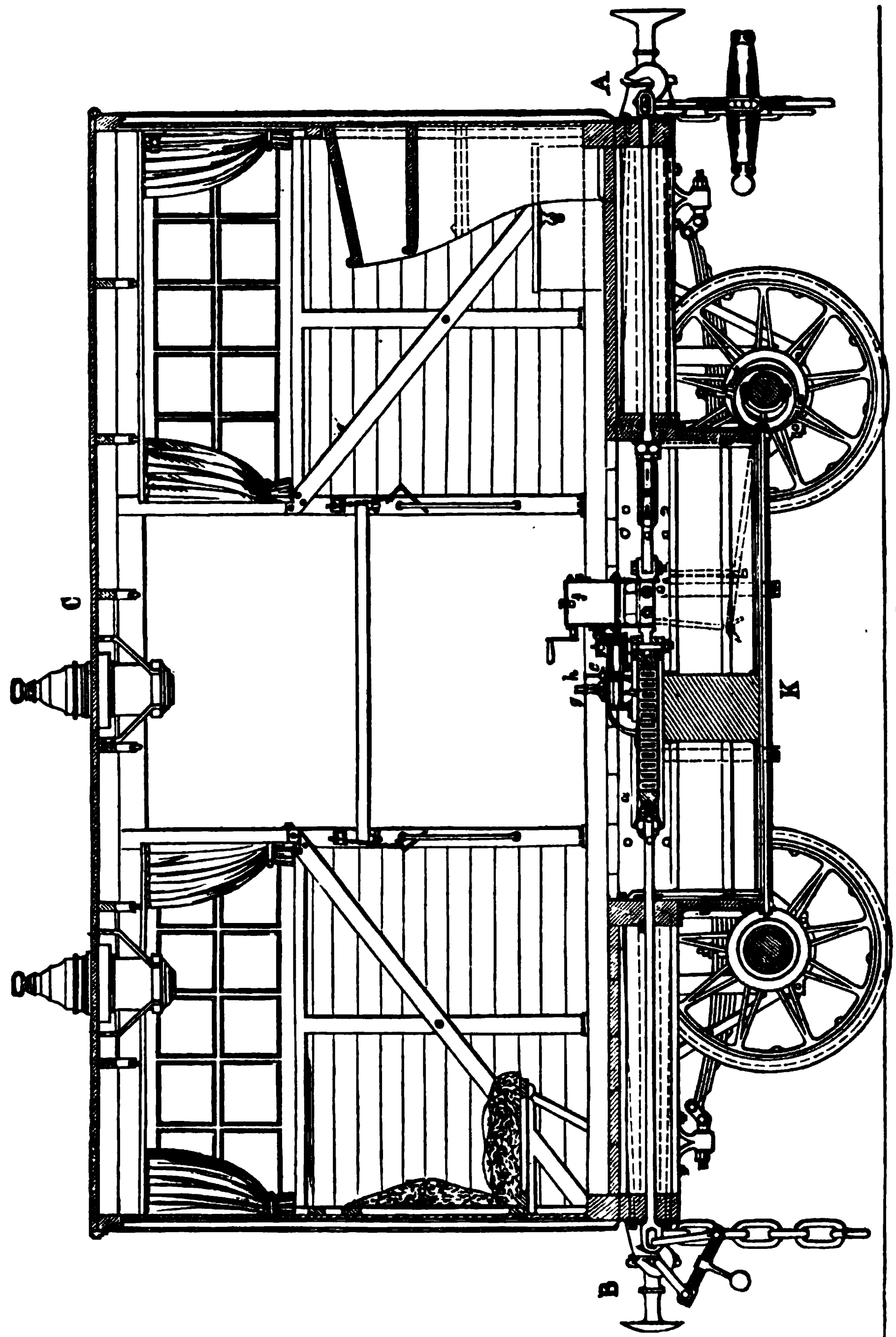


2893.

Elevation.

now we construct the tangents to the different points of this curve, and measure the angles of these tangents with the axis of the abscissæ; the geometrical value of these tangents, measured with a circle whose radius is one, will represent the velocities at the different points. We may thus trace the curve, $v = f'(t)$. Proceeding in the same manner with this second curve, we deduce

the curve of the accelerations, $j = f''(t)$. Multiplying the acceleration j at a determinate instant by the mass m, we obtain the force applied, $F = m f''(t)$. Thus, having constructed the curve of the accelerations, we have only to multiply the ordinates by a constant m, to find the retarding force at the different instants.



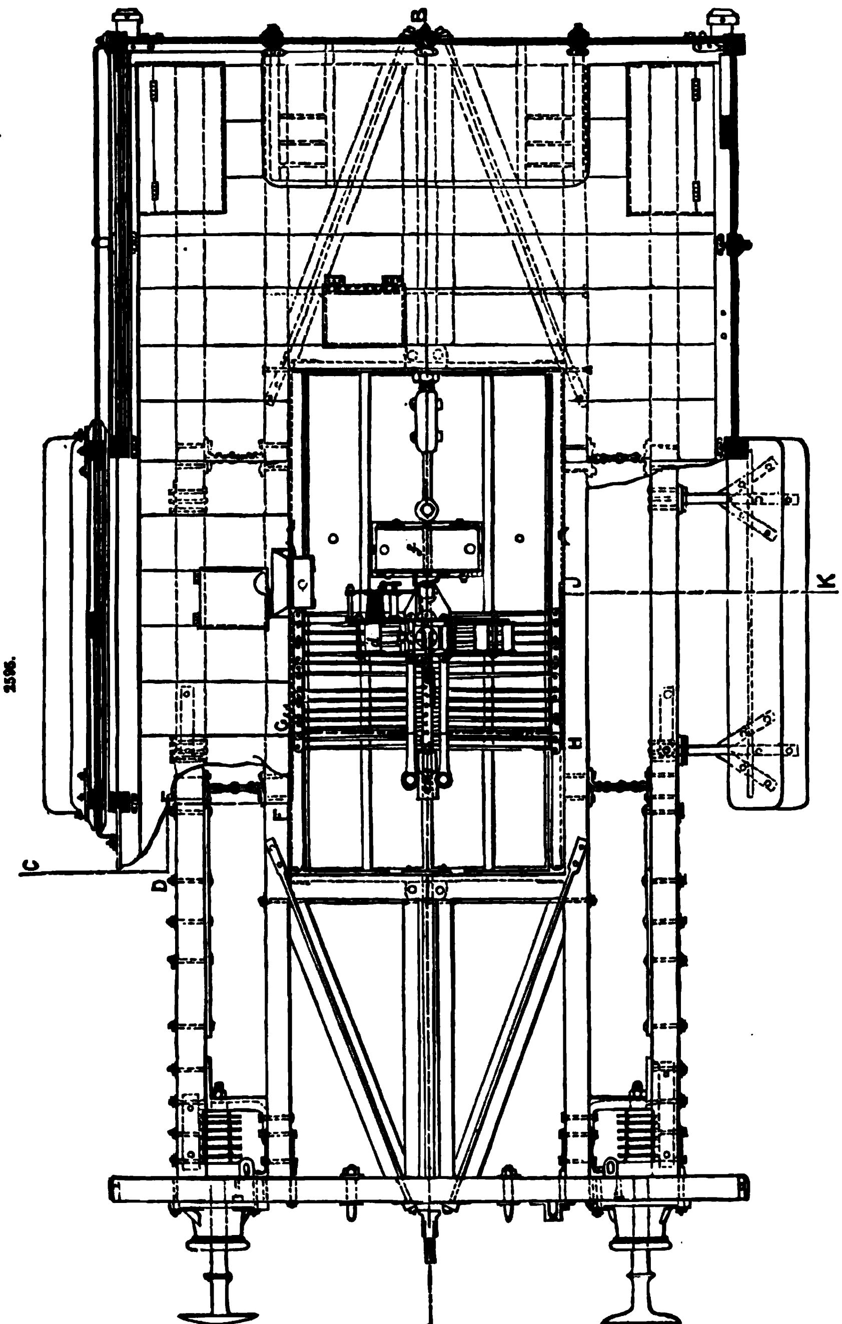
2594.

Section through A B.

Second Method.—This consisted in making experiments with a dynamometer. The apparatus is placed in a covered carriage which is attached immediately to the tender. The coupling rod is connected with the movable portion a of the dynamometrical spring; the fixed portion b of this

spring is firmly attached to the framework of the carriage. In this way, the tractive force is made to pass through the spring before it acts upon the carriage.

The movable portion *a* carries a vertical pencil *c*, which moves forwards or backwards in a vertical plane, according as the spring bends more or less. Beneath the pencil, a strip of paper



2598.

Section through L M N O.

moves in a horizontal plane around a roller *d*, which is kept in motion by a piece of clockwork in the box *f*.

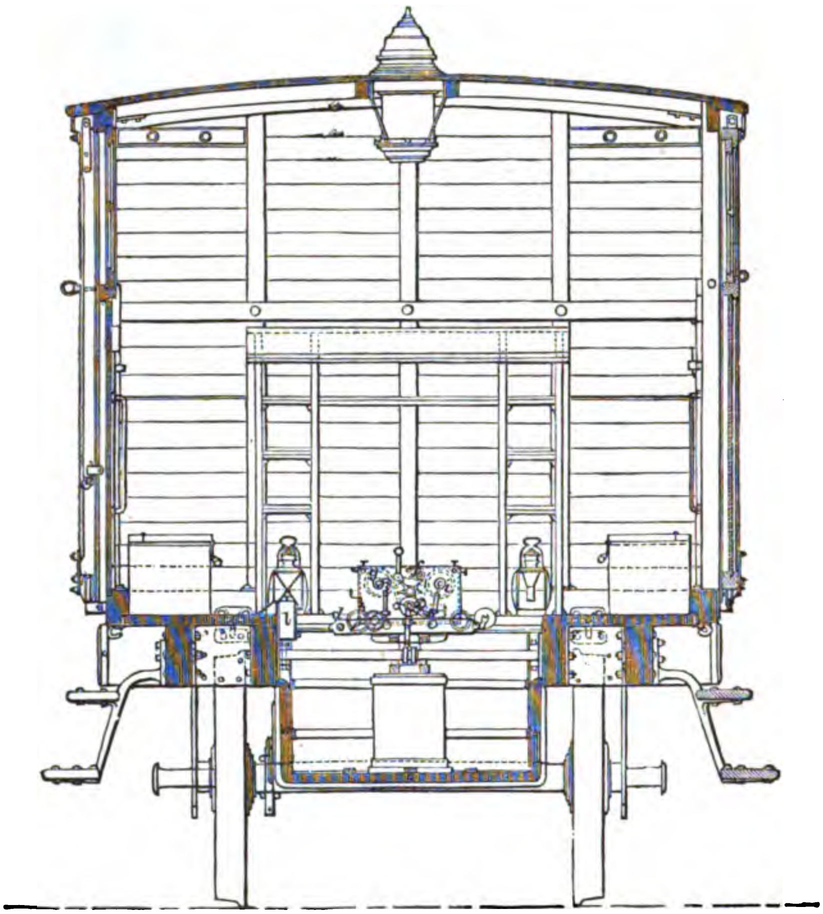
The distances are marked by hand, by means of the pencil *g*. They are also noted by means of a tell-tale in the box *l*. The chief wheel of this tell-tale is turned by a click, which is acted

upon by an eccentric placed on the axle of the carriage. The hand, or needle, makes one revolution a kilomètre: the divisions of the dial are of 10 mètres.

If this instrument should get out of order in rounding curves or while the train is being shunted at stations, it is easily rearranged by means of the kilomètre-posts on the line.

The pencil *h* serves to show the time, but it is necessary to mark the time by hand as well, because the strip of paper does not unroll itself at a uniform rate on account of the jolting which deranges the clockwork. The unrolling of a strip occupies about an hour; it may be replaced by another strip in five minutes

2596.



Section through C D E F G H J K.

A vane placed on the top of the carriage turns inside an indicator upon a divided circle. We are thus enabled to ascertain, when stationary, the angle which the wind makes with the axis of the carriage. By the side of the wind indicator is a compass, which gives the angle of the magnetic meridian with the axis of the carriage: we thus find the direction of the wind.

The temperature is shown by a thermometer.

Fig. 2597 gives the details of the dynamometrical spring. It is composed of fourteen pieces of $1^{m}\cdot 04$ in length; the ends of two adjacent pieces are connected by two bolts and two small washers. The spring is easily put together or taken to pieces; according as the tractive strain is to be more or less great, the whole or a part only may be made to act.

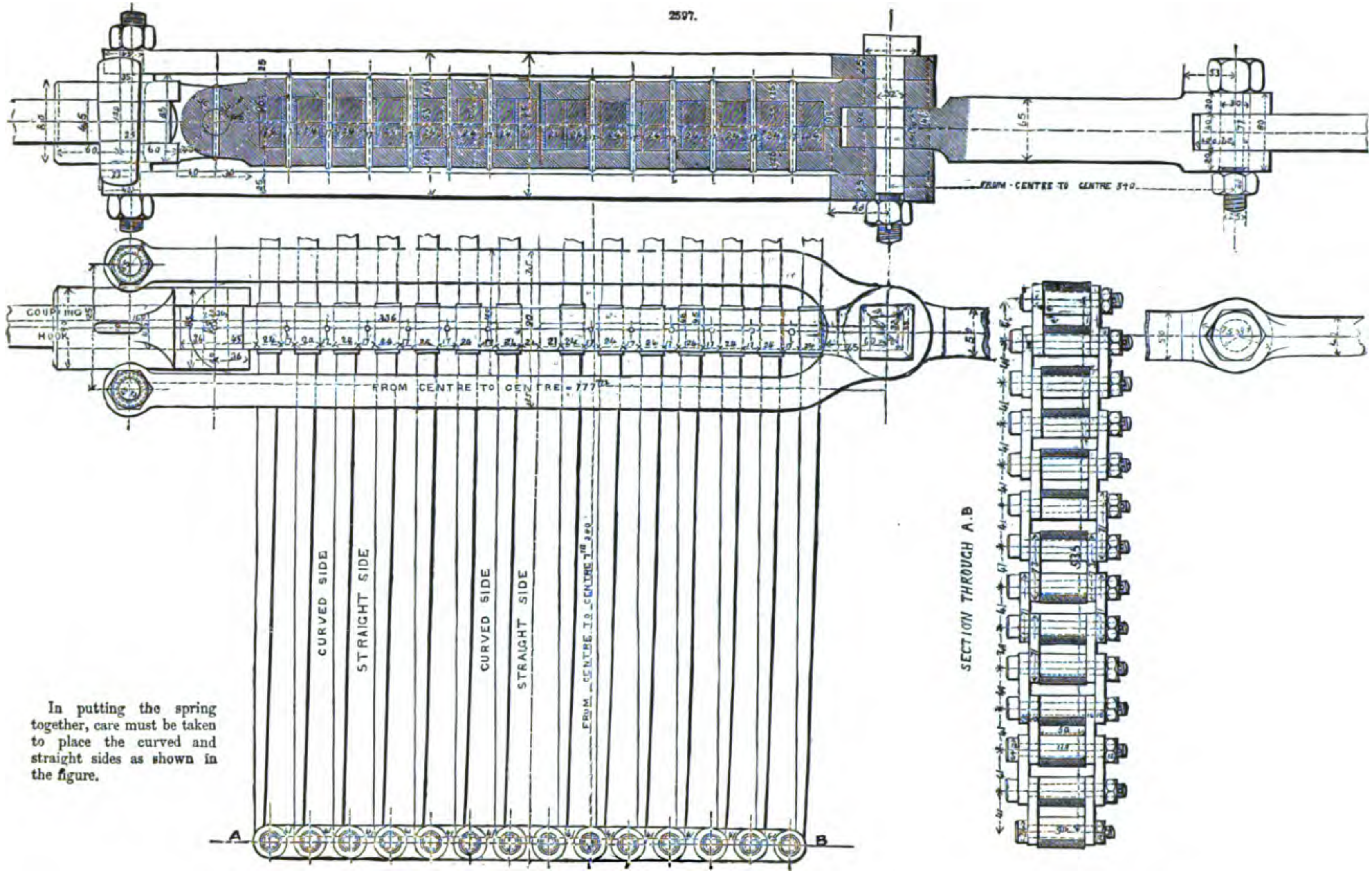
The deflections of the spring were carefully measured and noted with respect to the force exerted upon it, before it was used in the dynamometer carriage.

There is a scale for each coupling, namely, for two pieces, for four pieces, &c., and for fourteen pieces. The deflections are nearly rigorously proportional to the forces. This large spring, which was made by Messrs. Petin and Gaudet, is an excellent one; its flexibility was in no degree altered by the experiments made with it; to test it, its deflections were tried after it had been in use some time, and they were found to correspond exactly with those of the first trials.

To determine the resistance of passenger or goods trains, we always had recourse to the method of the dynamometer.

Resistance of a Single Carriage.—First Method.—The experiments connected with this subject

2597.



In putting the spring together, care must be taken to place the curved and straight sides as shown in the figure.

Spring for the Dynamometer.

were made between Epernay and Châlons. This portion of the line, 18 kilomètres in length, is eminently favourable to trials of this kind; the incline is uniform and very gradual (gradient = $0^m \cdot 4$), descending from Epernay to Châlons; besides this, the line is straight for a distance of 10 kilomètres in one place and 3 in another, and the curves are all short and of a long radius (radius = 2 to 3000 mètres).

The mean temperature was 25 degrees centigrade.

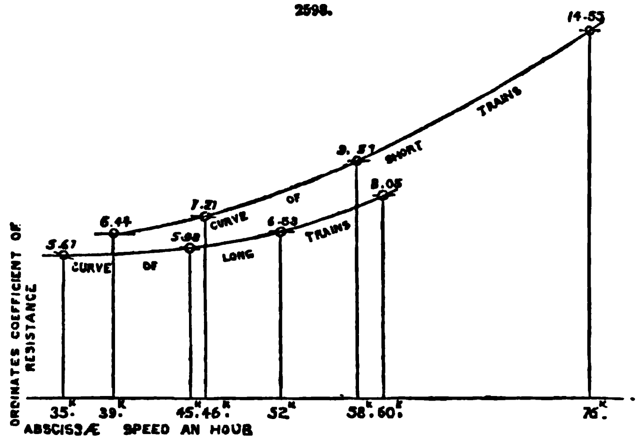
Mean Resistance of a Carriage driven at different Velocities.—The covered, four-wheeled, dynamometrical carriage with which the experiments were made was furnished with oil-boxes, and weighed 5500 kilogrammes.

		Mètres.
Dimensions	Height	2·30
	Breadth	2·60
	Length	4·90

Diameter of the wheels = 1 mètre.

This carriage was attached immediately to an engine, the operator inside being provided with a distance-counter and a chronometer. When the speed agreed upon was reached and had become uniform, at a given signal the carriage was detached from the engine, and left to itself till it stopped. This experiment was repeated several times with various initial velocities.

2598.



Curves of Resistances of Passenger Trains.

Scale of $\begin{cases} 2^{mm} \cdot 5 \text{ a kilomètre.} \\ 5^{mm} \text{ a kilogramme.} \end{cases}$

Five experiments of this nature were made, the results of which are given in the following Table;—

Nature of the Line. Gradients.	Initial Velocity in mètres a second.	Distance travelled.	Resistance deduced from the Formula.	Resistance corrected for Gravity.	Coefficient of Resistance a ton.
mill.	mètres.	mètres.	kils.	kils.	kils.
0·4	5·00	385	19·80	17·60	3·20
0·4	6·65	550	24·60	22·40	4·07
0·4	13·90	1333	44·20	42·00	7·63
0·4	13·90	1408	41·70	39·50	7·18
0·4	12·50	1347	35·30	33·10	6·03

It was necessary to reduce slightly the total resistance of the carriage, calculated by formula [β], on account of the inclination of the line. This was accomplished by supposing that the resistance was increased $0^k \cdot 4$; this gives for the carriage, $5 \cdot 5 \times 0 \cdot 4 = 2^k \cdot 2$. We shall see later that these figures correctly represent the influence of gravity upon the resistance of carriages on a gradient of $0^m \cdot 4$.

The last column of the preceding Table gives the mean coefficient of resistance for a covered carriage, such as the one we have described, rolling upon a straight and level line. Its increase with the initial velocity cannot fail to attract attention. We cannot give exactly the speed to which the foregoing coefficients correspond; for the mean speed is not equal to the mean of the extremes, that is, to the half of the initial velocity. It was observed that it was considerably less than this half, especially when the initial velocity was great, because the resistance increases with the speed.

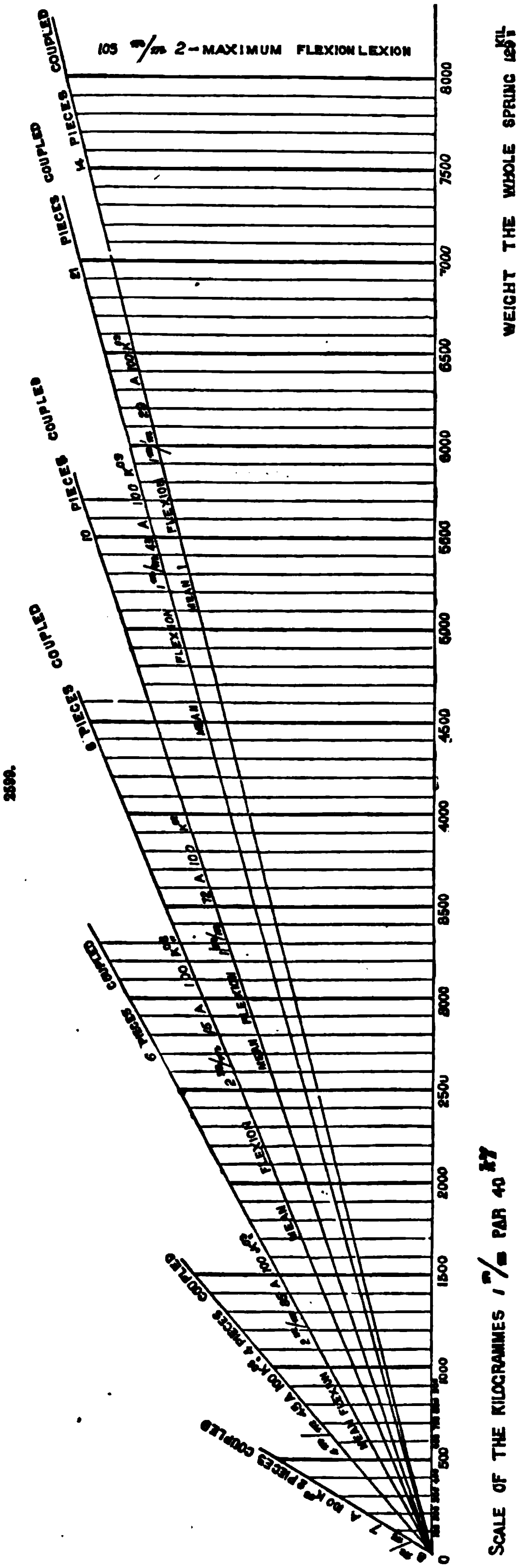
To determine the law of variation of the coefficients with the speed, we had recourse to the graphic method already described. This method is certainly of difficult application; errors of observation, errors that can hardly be avoided in the construction of the tangents may be multiplied from one curve to another; the results which we have obtained are, however, tolerably good. This method was applied to the first four experiments noted in the preceding Table.

Figs. 2599 to 2602 represent the four series of curves.

The extreme portions of the curves of acceleration are less accurate than the mean portions, on account of the graphical construction of the tangents. Grouping the figures given in Figs. 2599 to 2602, and making the correction for gravity, we obtain the following Table, which gives the law of the resistances on a level line from 0 to 35 kilomètres an hour.

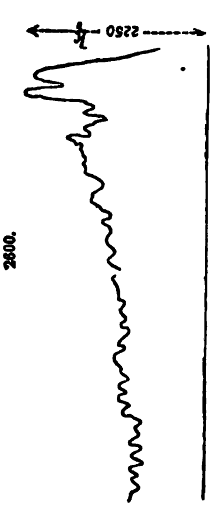
Speed an hour.	Resistance of the Carriage.	Coefficient of Resistance a ton.	Speed an hour.	Resistance of the Carriage.	Coefficient of Resistance a ton.
kilomètres.	kilogrammes.	kilogrammes.	kilomètres.	kilogrammes.	kilogrammes.
35	42	7·6	10 to 15	19	3·4
25 to 30	35	6·3	5 „ 10	14	2·5
20 „ 25	30	5·4	1 „ 5	11	2·0
15 „ 20	24	4·3	0	48	8·7 (starting)

2599.



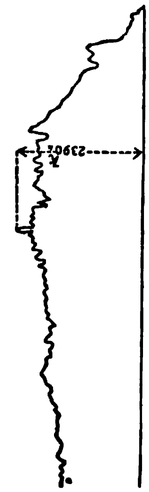
Dynamometer. Scale of the Flexions of the Spring.
Trials of the 10th May, 1865.

2600.



Dynamometrical Curves.
Train (2) 16 of the 5th June, 1866, starting from Charleville.

2601.

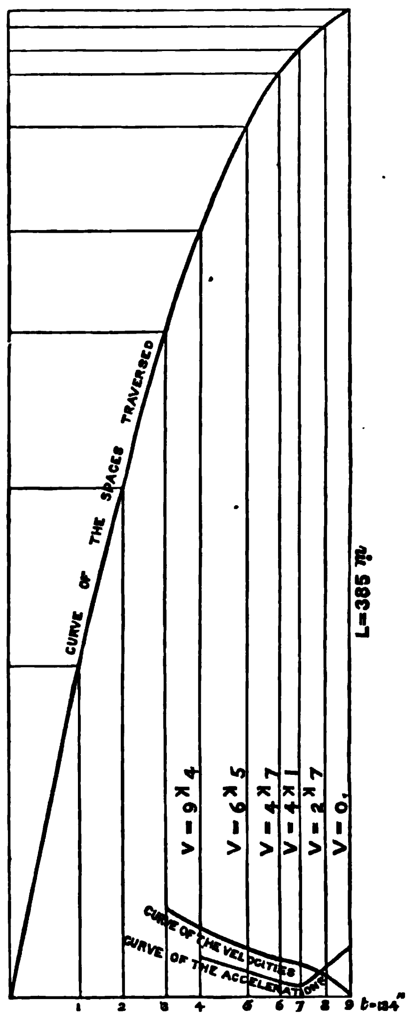


Train 75 of the 13th February, 1865, starting from d'Orry.

Second Method.—The dynamometer carriage being attached to an engine, its own resistance was first determined, which is, therefore, alone represented by the curve. It will be interesting to compare this result with those given previously.

Graphic Method applied to a Single Vehicle.

2602.



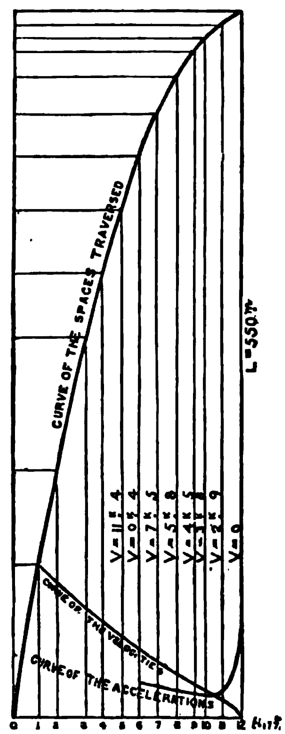
Scale $\left\{ \begin{array}{ll} \frac{1}{2} \text{ mill. a mètre.} & \text{Ordinates.} \\ \frac{1}{2} \text{ mill. a second.} & \text{Abscissæ.} \end{array} \right.$

First Experiment on the Rolling of the Dynamometer Carriage. Weight 5500^k.

Results.

For $V = 9^k \cdot 4$	$F = 29^k \cdot 20$	$f = 5^k \cdot 28$
„ $V = 6^k \cdot 5$	$F = 20^k \cdot 70$	$f = 3^k \cdot 76$
„ $V = 4^k \cdot 7$	$F = 13^k \cdot 90$	$f = 2^k \cdot 53$
„ $V = 4^k \cdot 1$	$F = 12^k \cdot 50$	$f = 2^k \cdot 27$
„ $V = 2^k \cdot 7$	$F = 20^k \cdot 70$	$f = 3^k \cdot 76$
„ $V = 0^k$	$F = 52^k \cdot 30$	$f = 9^k \cdot 50$

2603.



Scale $\left\{ \begin{array}{ll} \frac{1}{2} \text{ mill. for 2 mètres.} & \text{Ordinates.} \\ \frac{1}{2} \text{ mill. for 2 seconds.} & \text{Abscissæ.} \end{array} \right.$

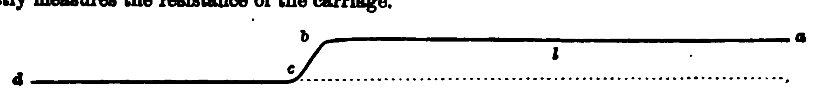
Second Experiment on the Rolling of the Dynamometer Carriage. Weight 5500^k.

Results.

For $V = 9^k \cdot 4$	$F = 21^k \cdot 00$	$f = 3^k \cdot 82$
„ $V = 7^k \cdot 5$	$F = 18^k \cdot 40$	$f = 3^k \cdot 33$
„ $V = 5^k \cdot 8$	$F = 17^k \cdot 00$	$f = 3^k \cdot 07$
„ $V = 4^k \cdot 5$	$F = 13^k \cdot 90$	$f = 2^k \cdot 70$
„ $V = 3^k \cdot 8$	$F = 13^k \cdot 60$	$f = 2^k \cdot 47$
„ $V = 2^k \cdot 9$	$F = 14^k \cdot 60$	$f = 2^k \cdot 65$
„ $V = 0^k$	$F = 46^k \cdot 50$	$f = 8^k \cdot 42$

The tractive power requisite for the carriage alone is very small, and must be measured in a special manner. Indeed, the smallest error in drawing the line of the abscissæ, due either to the play of the paper upon the rollers, or to a faulty arrangement of the pencil, would be a considerable fraction of the quantity to be measured; we were thus led to adopt an artifice. The carriage was first drawn at a uniform speed, the line *a b* being marked by the pencil; the engine was then

suddenly detached, and the same pencil marked the line cd; the distance l between the two lines exactly measures the resistance of the carriage.



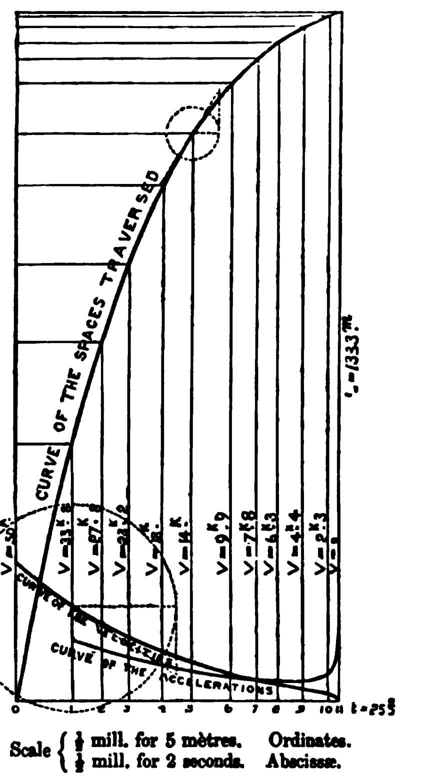
The resistance was then found to be

25 kilogrammes at the speed of 25 kilomètres an hour, say $4^{k}\cdot54$ a ton.
50 „ „ 50 „ „ $9^{k}\cdot10$ „

These figures are a little less than those found by the first method; this is owing to the tenders having covered a portion of the front of the carriage.

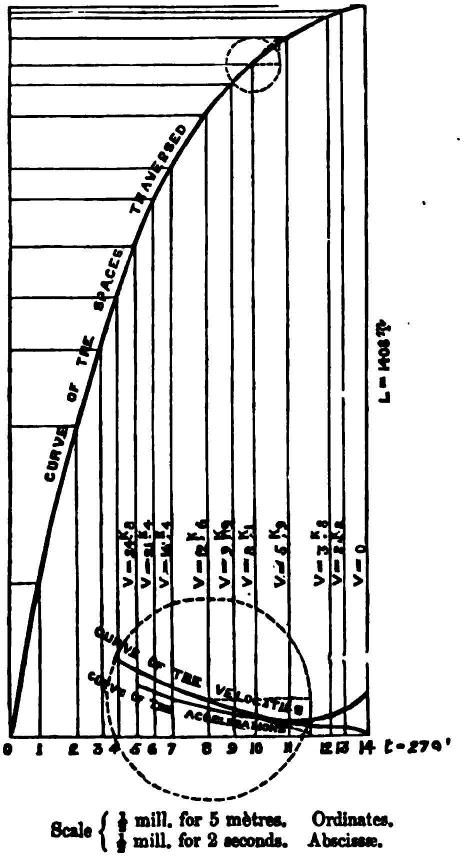
Graphic Method applied to a Single Vehicle.

2604.



Scale { $\frac{1}{2}$ mill. for 5 mètres. Ordinates. / $\frac{1}{2}$ mill. for 2 seconds. Abscissæ. }

2605.



Scale { $\frac{1}{2}$ mill. for 5 mètres. Ordinates. / $\frac{1}{2}$ mill. for 2 seconds. Abscissæ. }

Third Experiment.

Results.

For V = 33^{k}·8	F = 44^{k}·16	f = 8^{k}·05
„ V = 27^{k}·8	F = 37^{k}·0	f = 6^{k}·78
„ V = 23^{k}·2	F = 32^{k}·30	f = 5^{k}·87
„ V = 18^{k}·0	F = 26^{k}·78	f = 4^{k}·88
„ V = 14^{k}·0	F = 22^{k}·09	f = 4^{k}·02
„ V = 9^{k}·9	F = 17^{k}·39	f = 3^{k}·16
„ V = 7^{k}·8	F = 15^{k}·45	f = 2^{k}·82
„ V = 6^{k}·3	F = 15^{k}·0	f = 2^{k}·72
„ V = 4^{k}·4	F = 13^{k}·8	f = 2^{k}·52
„ V = 2^{k}·3	F = 21^{k}·1	f = 3^{k}·84
„ V = 0^{k}	F = 50^{k}·6	f = 9^{k}·20

Fourth Experiment.

Results.

For V = 24^{k}·8	F = 34^{k}	f = 6^{k}·17
„ V = 21^{k}·4	F = 30^{k}·5	f = 5^{k}·54
„ V = 16^{k}·4	F = 25^{k}	f = 4^{k}·55
„ V = 12^{k}·6	F = 20^{k}·8	f = 3^{k}·78
„ V = 9^{k}·9	F = 17^{k}·2	f = 3^{k}·12
„ V = 8^{k}·1	F = 11^{k}·6	f = 2^{k}·12
„ V = 5^{k}·9	F = 11^{k}·1	f = 2^{k}·02
„ V = 3^{k}·8	F = 11^{k}·4	f = 2^{k}·07
„ V = 2^{k}·8	F = 17^{k}·2	f = 3^{k}·12
„ V = 0^{k}	F = 29^{k}·5	f = 5^{k}·35

The coefficient of resistance a ton, at starting, $8^{k}\cdot7$, given by the last Table, was also verified approximatively by means of a small dynamometer with a spiral spring, placed in the chain, by which the carriage was gently drawn until its inertia was overcome.

Resistance of Engines at different Velocities.—First Method.—The experiments in this case were made between Epernay and Châlons; the engines and tenders were carefully weighed at Epernay before starting, and again on their return, the object being to determine the resistance of engines under ordinary conditions, that is, having their steam up and being properly greased.

The engines were started at different velocities, and when the speed had become uniform, the steam was shut off and the engine left to itself till it stopped. The distance and the time were measured by a chronometer and a distance-counter.

The initial motive force is composed, not only of the force due to the rectilineal velocity of the total mass, but also of the force due to the rotation of the revolving masses (see Note A, later). The engines submitted to these experiments were of two kinds, No. 15 a goods engine, and No. 14 used for mixed trains (Table I.).

V being the velocity at the circumference, in mètres a second, the motive force of rotation of the engine axles will be expressed as follows;—

$18 \cdot 4 \times V^2$ for wheels of $1 \cdot 20$ mètre.
$20 \times V^2$ " $1 \cdot 30$ "
$27 \cdot 4 \times V^2$ " $1 \cdot 68$ "

Admitting this, let

s be the space traversed;
M, the total mass in motion;
V, the initial velocity in mètres a second,
a, the known resistance of the auxiliary carriage;
x, the unknown resistance of the motor (engine and tender);
b, a known term (depending on the revolving masses);

we have the formula

$$\left(\frac{1}{2} M + b\right) V^2 = (a + x) \times s. \qquad [\gamma]$$

As an example of the application of this formula [γ], let us take trial No. 1, Table II.

The mixed engine No. 249, system 14, the tender 440, and the auxiliary carriage, in all three vehicles, were driven at a speed of 20 kilomètres an hour, and they stopped in 427 mètres; the time spent in traversing this space was 2 minutes 30 seconds, from which it follows that the mean speed was 10 kilomètres an hour.

We have, besides,

$$\frac{1}{2} M = \frac{1}{19 \cdot 62} \times (50400 + 5500) = 2850.$$
$$b = 25 + 2 \times 27 \cdot 4 + 3 \times 18 \cdot 4;$$

whence

$$b = 135,$$
$$V^2 = 5 \cdot 55^2 = 30 \cdot 8,$$
$$a = 19 \cdot 80, \qquad s = 427.$$

Substituting these values in the equation [γ], we find $2985 \times 30 \cdot 8 = (19 \cdot 80 + x) \times 427$; whence $x = 196$.

Thus the mean resistance of the *engine and tender*, during the time of retardation, was 196 kilogrammes; if the line had been perfectly level, the resistance would have been diminished by $0 \cdot 4 \times 50 \cdot 4 = 20^k \cdot 16$; say 20 kilogrammes. There remain 176 kilogrammes, which makes $3^k \cdot 50$ a ton.

Notwithstanding a few variations, which may be attributed to the condition of the line and to different degrees of lubrication, it will be seen that the coefficients of Table II. may be arranged so as to furnish a law of continuous increase with the initial velocity. The variation of the coefficients from one engine to another of the same type, with an equal initial velocity, may be explained by the more or less perfect working of the parts subject to friction. For different types, besides this reason, the variation depends upon the dissimilarity of the mechanism. The relative inferiority of the coefficients for engines Nos. 253 and 0·155 is owing to the tenders of these engines being provided with oil-boxes.

From Table II. we find that for the two mixed engines the coefficient f of the mean resistance a ton has the following values;—

For an initial velocity of 20 to 29 kilomètres, say a mean velocity of $11^k, f = 3^k \cdot 20$
" " 30 to 39 " " " $15^k, f = 4^k \cdot 00$
" " 40 to 49 " " " $20^k, f = 4^k \cdot 35$
" " 50 to 60 " " " $23^k, f = 5^k \cdot 70$

The goods engine No. 0·123 gives;—

For an initial velocity of 20 to 25 kilomètres, say a mean velocity of $9^k, f = 5^k \cdot 32$
" " 25 to 35 " " " $12^k, f = 6^k \cdot 43$
" " 35 to 40 " " " $16^k, f = 7^k \cdot 52$

The results of engine No. 0·155 cannot be combined with those of engine No. 0·123, because they are not sufficiently numerous. The graphic method of the curves of acceleration was not applied to these experiments.

TABLE I.—KINDS OF ENGINES SUBMITTED TO THE DYNAMOMETRICAL EXPERIMENTS.

	Free Wheels. No. 1.	Free Wheels. No. 2β.	Crampton. No. 8.	Mixed. No. 7.	Mixed. No. 12.	Mixed. No. 14.	Goods. No. 11.	Goods. No. 15.	Goods. No. 20.	Eight Wheels coupled. No. 17β.
Number of driving axles	1	1	1	2	2	2	3	3	3	4
Total number of axles	3	3	3	3	3	3	3	3	3	4
Weight loading the driving wheels (with 15^c of water)	$9,852^k$	$11,030^k$	$10,275^k$	$18,800^k$	$21,400^k$	$19,600^k$	$26,791^k$	$29,309^k$	$33,000^k$	$46,310^k$
Total weight (with 15^c of water)	$22,040^k$	$26,978^k$	$27,275^k$	$25,694^k$	$25,500^k$	$28,805^k$	$26,791^k$	$29,309^k$	$33,000^k$	$46,310^k$
Diameter and length of the cylinders	38^c 56^c	38^c 56^c	40^c 56^c	42^c 56^c	42^c 56^c	42^c 56^c	44^c 60^c	42^c 61^c	44^c 66^c	50^c 66^c
Diameter of the driving wheels	$1^m\cdot69$	$2^m\cdot00$	$2^m\cdot30$	$1^m\cdot69$	$1^m\cdot69$	$1^m\cdot68$	$1^m\cdot43$	$1^m\cdot30$	$1^m\cdot40$	$1^m\cdot26$
Position of the cylinders	outside	outside	outside	inside	inside	outside	inside	outside	outside	outside
Distance between the extreme axles	$3^m\cdot015$	$3^m\cdot875$	$4^m\cdot500$	$3^m\cdot560$	$4^m\cdot240$	$3^m\cdot520$	$3^m\cdot435$	$3^m\cdot300$	$3^m\cdot550$	$3^m\cdot950$
Dimensions of the journals: 1st axle	$15^c/17^c$	$16^c/24^c$	$15^c/26^c$	$16^c/18^c$	$16^c/18^c$	$15^c/22^c$	$16^c/19^c$	$16^c/20^c$	$18^c/23^c$	$17^c/25^c$
2nd axle	$16^c/15^c$	$16^c/18^c$	$13^c/22^c$	$17^c/16^c$	$16^c/18^c$	$16^c/18^c$	$17^c/17^c$	$16^c/18^c$	$18^c/23^c$	$17^c/25^c$
3rd axle	$15^c/17^c$	$15^c/17^c$	$18^c/26^c$	$16^c/18^c$	$13^c/15^c$	$16^c/18^c$	$16^c/19^c$	$16^c/18^c$	$18^c/23^c$	$20^c/25^c$
4th axle	$15^c/17^c$	$15^c/17^c$	$18^c/26^c$	$16^c/18^c$	$13^c/15^c$	$16^c/18^c$	$16^c/19^c$	$16^c/18^c$	$18^c/23^c$	$17^c/25^c$
Length of the piston-rods	$1^m\cdot375$	$1^m\cdot650$	$2^m\cdot070$	$1^m\cdot400$	$1^m\cdot900$	$1^m\cdot760$	$1^m\cdot550$	$1^m\cdot720$	$1^m\cdot650$	$2^m\cdot400$
Stamp of the boiler	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.	8 atmos.
Surface of the fire-box	$5^{mq}\cdot06$	$6^{mq}\cdot34$	$6^{mq}\cdot65$	$6^{mq}\cdot36$	$7^{mq}\cdot41$	$7^{mq}\cdot20$	$7^{mq}\cdot25$	$7^{mq}\cdot20$	$8^{mq}\cdot05$	$9^{mq}\cdot71$
Surface of the tubes	$62^{mq}\cdot85$	$69^{mq}\cdot35$	$84^{mq}\cdot62$	$81^{mq}\cdot96$	$74^{mq}\cdot49$	$93^{mq}\cdot22$	$91^{mq}\cdot55$	$93^{mq}\cdot22$	$113^{mq}\cdot00$	$183^{mq}\cdot92$
Total heating surface	$67^{mq}\cdot91$	$75^{mq}\cdot69$	$91^{mq}\cdot27$	$88^{mq}\cdot32$	$81^{mq}\cdot90$	$100^{mq}\cdot42$	$98^{mq}\cdot80$	$100^{mq}\cdot42$	$121^{mq}\cdot05$	$193^{mq}\cdot63$
Length of the tubes	$3^m\cdot760$	$3^m\cdot011$	$3^m\cdot460$	$4^m\cdot055$	$3^m\cdot187$	$3^m\cdot994$	$4^m\cdot017$	$3^m\cdot994$	$4^m\cdot100$	$5^m\cdot000$
Mean diameter of the cylindrical parts	$0^m\cdot970$	$1^m\cdot200$	$1^m\cdot266$	$1^m\cdot198$	$1^m\cdot258$	$1^m\cdot256$	$1^m\cdot258$	$1^m\cdot256$	$1^m\cdot320$	$1^m\cdot500$
Volume of water	$2^{mc}\cdot040$	$2^{mc}\cdot628$	$3^{mc}\cdot355$	$3^{mc}\cdot444$	$2^{mc}\cdot800$	$3^{mc}\cdot445$	$2^{mc}\cdot999$	$3^{mc}\cdot445$	$3^{mc}\cdot926$	$5^{mc}\cdot220$

Note.—The new engines with eight wheels coupled, employed upon steep gradients, have their boilers 28 centimètres longer than the old ones, type 17β. Besides this, the pressure in these new engines, numbered 0·526 to 0·600, has been raised to 9 atmospheres.

TABLE II.—EXPERIMENTS ON THE RESISTANCE OF ENGINES AND TENDERS TO MOTION.

Experiments.	Type of Engine and Tender.	Nature of the Line.	Initial Velocity an hour.	Distance Run.	Time in seconds.	Mean Velocity an hour.	Mean Resistance by calculation.	Correction for Gravity.	Mean Resistance on a Level: Total.	Mean Resistance on a Level: a ton.	Mean of the Coefficients.
			kiloms.	mètres.		kiloms.	kilogs.	kilogs.	kilogs.	kilogs.	kilogs.
1	Mixed, 249.—Type 14. Tender, 440.—Grease-boxes. Weight 50,000 kilogrammes.	Gradients = 0·4 millimètre.	20	427	150	10	196	20	176	3·50	3 48
2			20	430	157	10	194	20	174	3·46	
3			30	688	194	12	292	20	272	5·38	4 59
4			33	840	210	14	256	20	236	4·68	
5			33	1115	269	15	187	20	207	4·20	
6			38	1465	304	17	183	20	203	4·10	
7			45	1640	280	21	243	20	223	4·42	4·81
8			45	1437	280	18	283	20	263	5·20	
9			51	2137	362	21	237	20	257	5·20	5·67
10			55	2047	348	21	283	20	303	6·15	
11	Mixed, 253.—Type 14. Tender, 484.—Oil-boxes. Weight 50,500 kilogrammes.		26	740	196	14	188	20	168	3·30	2·92
12			26	910	280	12	149	20	129	2·54	
13			34	1218	290	15	186	20	166	3·28	3·41
14			32	1350	319	15	200	20	180	3·54	
15			43	1730	350	18	203	20	183	3·61	3·90
16			46	2082	362	21	190	20	210	4·20	
17			60	2626	379	25	267	20	287	5·74	5·74
18	Goods, 0·123.—Type 15. Tender, 118.—Grease-boxes. Weight 45,300 kilogrammes.		20	322	130	9	242	18	224	4·92	5·32
19			22	346	130	10	273	18	255	5·63	
20			20	340	130	9	227	18	245	5·40	
21			26	380	132	9	350	20	330	7·28	6·43
22			26	404	135	11	318	20	298	6·53	
23			26	450	146	11	283	20	263	5·82	
24			30	508	150	12	339	20	319	7·00	
25			32	610	165	13	312	20	292	6·45	
26			33	700	171	15	290	20	270	5·96	
27			30	680	170	14	246	20	266	5·88	
28			40	842	182	17	318	20	338	7·45	7·52
29			39	792	180	16	326	20	346	7·60	
30	Goods, 0·155.—Type 15. Tender, 499.—Oil-boxes. Weight 48,600 kilogrammes.		38	990	218	16	276	20	256	5·25	5·59
31			40	1015	214	17	307	20	287	5·93	

Second Method.—Each double journey, from Epernay to Châlons and back, was made with two engines; the dynamometer being placed in the middle, the second engine, drawn on the outward journey, drew, in its turn, the first engine on the return. The hind engine had its regulator closed, its steam shut off, and its waste-pipés open. In the middle of the journey the train was stopped for the purpose of greasing the cylinders of the engine which was being drawn. The types experimented upon were four in number; the results obtained will be found in Table III.

It will be seen that at the ordinary speed, the resistance a ton of the *engine and tender*, for the rolling of these vehicles and the friction of their mechanism when not at work, reaches the following values;—

Goods engine (type 15) .. .. $V = 24^k$, $f = 9^k \cdot 52$
" (type 20) .. .. $V = 26^k$, $f = 10^k \cdot 24$
Mixed engine (type 14) .. .. $V = 45^k$, $f = 6^k \cdot 41$
Engine with free wheels (type 1) $V = 45^k$, $f = 5^k \cdot 48$

The figures found by this method are naturally greater than those obtained by the first process; the speed is generally greater, and the greasing of the cylinders and slide-valves is not the same; here we travel several kilomètres without steam in the cylinders and without grease; in the first method the engine goes but a few hundred mètres after the regulator is closed.

The following are two immediate applications which may be made of the figures we have given above.

1. At their normal speed, 6-wheeled goods engines descend alone, without steam, inclines of 9 to 10 millimètres; and mixed and free-wheeled engines descend alone inclines of 5 to 6 millimètres.

2. To find the total work developed by an engine in front of a train, we must add to the work measured by the dynamometer the work absorbed by the engine itself, both by its transport and by its friction. This may be done by multiplying the above coefficients by the weight of the motor and by the speed.

Type 20 gives a higher coefficient than type 15, though the latter has smaller wheels. The greater resistance of type 20 is probably due to the larger dimensions of the cylinders, and, in general, to a little more friction in the mechanism.

The influence of the speed upon the resistance is clearly seen from the Table; we shall return to this subject later.

TABLE III.—DYNAMOMETRICAL EXPERIMENTS ON THE RESISTANCE OF ENGINES AND TENDERS IN MOTION.

Type of Engine.	Number of the Engine.	Distance run by the Engine since the last general repairs.	Type of Tender.	Weight of the Engine and Tender.	Number of Kilomètres experimented on.	Mean Speed an hour.	Total mean Resistance.	Resistance a ton of Engine and Tender.	Mean of the Resistances a ton.
		kiloms.		tons.	kiloms.	kiloms.	kiloms.	kiloms.	kiloms.
Goods.—Type 15. Six wheels coupled. D = $1^m \cdot 30$.	0·151	18,231	Four wheels, grease-boxes .. .. .. D = $1^m \cdot 20$	49 to 50	6	15	437	8·90	9·80
				..	10	24	497	10·00	
					4	27	515	10·50	
	0·123	8,013	Four wheels, oil-boxes D = $1^m \cdot 20$	50 to 51	8	22	416	8·20	9·25
				..	4	34	523	10·30	
								Mean	9·52
Goods.—Type 20. Six wheels coupled. D = $1^m \cdot 40$.	0·295	16,403	Four wheels, grease-boxes .. .. .. D = $1^m \cdot 14$	53 to 55	11	23	529	9·62	10·24
				..	17	30	582	10·86	
Mixed.—Type 14. Four wheels coupled. D = $1^m \cdot 70$.	249	12,895	Four wheels, grease-boxes .. .. .. D = $1^m \cdot 20$	47 to 49	11	30	347	6·92	7·73
				..	10	49	417	8·55	
					5	62	588	12·58	
	214	20,943	Four wheels, grease-boxes .. .. .. D = $1^m \cdot 20$	51 to 52	15	29	293	6·01	5·65
				..	8	27	272	5·30	
	189	8,185	Four wheels, oil-boxes D = $1^m \cdot 20$	51 to 53	16	35	300	5·81	5·86
				..	5	43	307	5·92	
								Mean	6·41
Free wheels.—Type 1. D = $1^m \cdot 70$.	77	19,623	Four wheels, grease-boxes .. .. .. D = $1^m \cdot 00$	37 to 38	15	50	232	6·05	5·48
				..	2	41	185	4·92	

Resistance of Locomotives and Tenders at Starting.—There is a special degree of friction at starting, because the condition of the surfaces with respect to lubrication is not the same then as it is after the wheels have made a few revolutions. For each vehicle a minimum force is necessary to overcome its inertia; to determine this force accurately, it must be applied gradually till the mass is set in motion. This is hardly possible when a locomotive is used; in almost every case more force is applied than is necessary. We succeeded, however, in fulfilling the required conditions in a satisfactory degree, by drawing a heavy mixed engine with a small one of free wheels; the latter was obliged to exert all its strength to move the larger engine, the inertia of which was, consequently, gently overcome. It was found in this way that the mixed engine, type 14, with its tender, required a force of 820 kilogrammes, say $15^k \cdot 90$ a ton, and the goods engine, type 15, a force of $19^k \cdot 70$ a ton.

These figures show with tolerable accuracy the value of the friction at starting. If now we start more energetically, the greatest force shown by the curve is not employed merely to overcome the friction, but to give acceleration to the mass acted upon. We have seen applied, to start a mixed engine, a force of 40 kilogrammes a ton, yet the shock produced could not be called violent; and such starts as these are of daily occurrence.

Resistance of Tenders alone.—Experiments were made upon tenders alone by means of the dynamometer, the results of which experiments are given in Table IV. The mean resistance is $5^k \cdot 16$ a ton at a speed of 27 to 32 kilomètres, and $7^k \cdot 00$ a ton at a speed of 45 kilomètres.

TABLE IV.—DYNAMOMETRICAL EXPERIMENTS ON THE RESISTANCE OF TENDERS IN MOTION.

Type of Tender.	Number of the Tender.	Weight of the Tender.	Number of Kilomètres experimented on.	Mean Speed an hour.	Total mean Resistance.	Resistance a ton.	Mean of the Resistances.
		k.		k.	k.	k.	k.
Grease-boxes, four wheels. D = $1^m \cdot 20$.	440	19,510	8	29	99	5·07	5·16
		18,600	4	27	93	4·98	
		18,600	5	32	101	5·43	
		19,510	2	44	128	6·56	7·00
	174	21,400	14	45	160	7·45	

Resistance of Engines with Four Axles coupled.—Four experiments were made to determine in a special manner the resistance of engines with four axles coupled. We had at our disposal a

straight piece of line of only 300 mètres in length; consequently it was impossible to exceed a very moderate speed. The temperature was at + 5 degrees centigrade.

Two engines, Nos. 0·177 and 0·168, were used in these experiments, which were repeated in order to obtain a mean; the former engine had its steam up, the latter was cold. The dynamometrical curve gives the following resistances;—

1. Engine 0·177 (weight of the engine and tender = 63100 kils.).

First trial	1460 kils.
Second trial	1470 „
Mean	1465 „

2. Engine 0·168 weight of the engine and tender = 64700 kils.).

First trial	1300 kils.
Second trial	1370 „
Mean	1335 „

Mean of the two results, 1400 kils., say $21^{k} \cdot 50$ a ton. The speed varied from 6 to 10 kilomètres an hour.

The foregoing experiments were made with the greatest care, yet they are not so trustworthy as those made on the 10 to 12 kilomètres between Epernay and Châlons. The resistance of the engine with four axles coupled was found to be at starting 30 kilogrammes a ton.

Resistance of Trains in general.—The dynamometer was always employed to determine the force upon the couplings of the tender due to the resistance of the train. Figs. 2606 to 2609 are an example of the method of experimenting and calculating applied to a portion of the train (E) 74 of the 22nd March, 1867. It is the case of a goods train drawn by an engine with eight wheels coupled upon a steep incline (15 millimètres a mètre).

The time is marked every 30 seconds; the distance every 500 mètres, and when the speed decreased much, every 250 mètres.

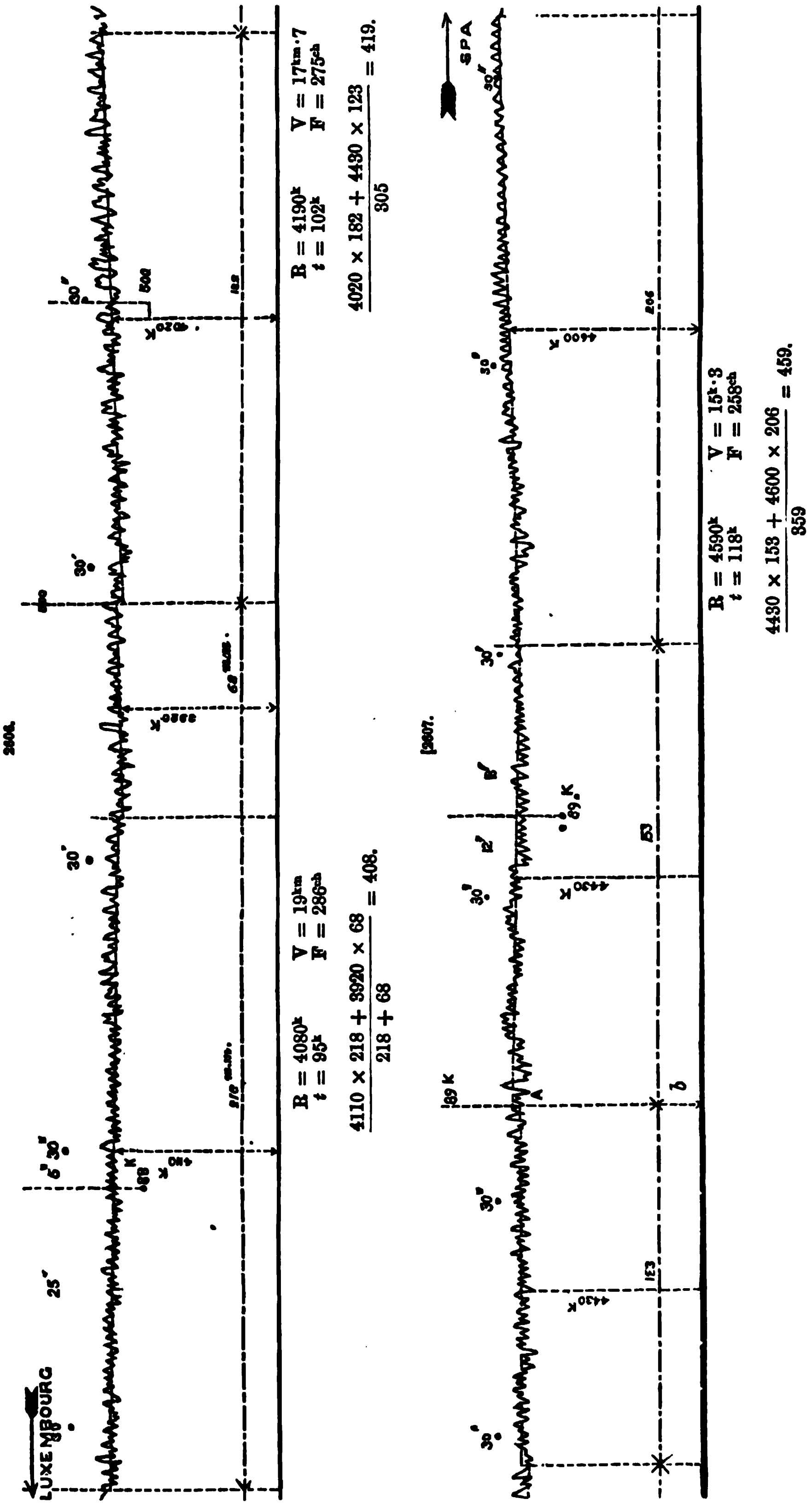
The whole of that portion of the Figure which is represented by full lines was drawn at the time of making the experiments; that portion indicated by dotted lines was executed afterwards for the purposes of calculation. As the paper moved from left to right, the curve must be studied from right to left. The pencil which marks the force not being in the same vertical plane as those which mark the time and the distance, the curve must be removed a distance of 95 millimètres, which is the distance between the two planes; the line *a b* represents the force at the moment of passing post 89. The force, the time, the speed, and the work may be calculated for each period of distance.

For example, between posts 88½ and 89 the quadrature of the curve is made by means of two trapeziums; we deduce from it the fact that the mean force was 4190 kilogrammes throughout this distance. There are 3 points representing 30 seconds each, plus a fraction corresponding to 12 seconds; total, 102″. It follows that the speed was $17^{k} \cdot 7$ an hour, and that the work was 275 horse-power.

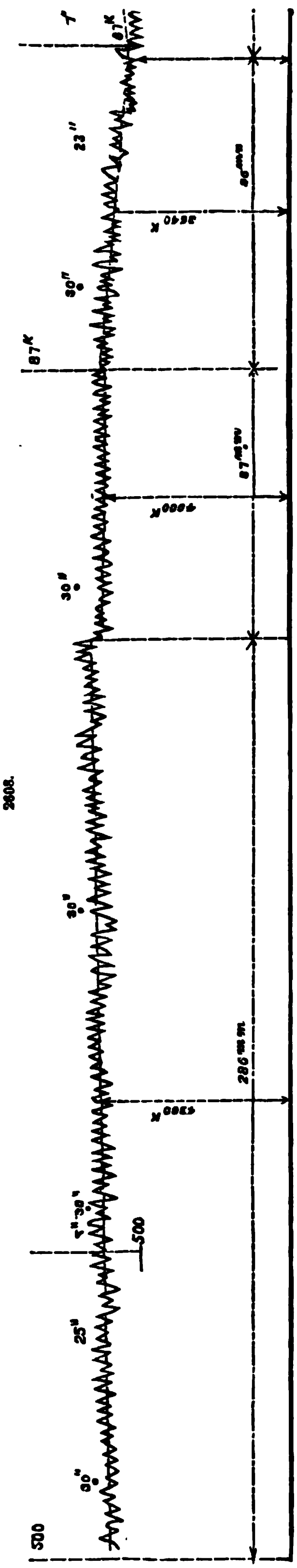
Table V. shows the arrangement of the figures copied from the roller, with the results of calculation.

Table V.—Train No. (E) 74 of the 22nd March, 1867, from Vielsalm to Gouvy.
Engine No. 0529. (Type with four axles coupled.)

Kilo-mètre-posts.	Nature of the Line.	Curve of the Line.	Gross weight of the train.	Number and kind of vehicles.	Atmo-spheric con-ditions.	Force noted by the dynamo-meter.	Mean of the forces.	Resistance a ton. Effec-tive.	Resistance a ton. After correc-tion for grav.	Speed au hour.	Mean of the speeds.	Work in horse-power.	Mean of the work.	Observations.
			tons.			kilogs.	kils.	kils.	kils.	kiloms.	kils.			
90	..	..	233	16	A little snow and wind.									G = gradient.
89·50	..	Mini-mum radius of the curves 400 mètres.	..	Car-riages (all lu-bricated with oil).		3530	..	..	..	12·1	..	159		Between posts 87 and 86, the highest limit of the oscillations of the curve corresponded to 5200 kilogs.
89	G = 15 mill.		..			4590	..	..	..	15·3	..	258		
88·50	..		..			4190				17·7		275		
88	..		..		$t = +4°$	4080				19·0		286		
87·50	..		..		..	4110				19·3		293		
87	G = 9 & 15 mill.		..	..	..	3700				20·3		278		
86·50	G = 18 mill.	..	..	..	..	4280				15·3		242		The quantity of water consumed from Vielsalm to Gouvy, 1980 litres.
86·25	..	..	..	..	..	4730	4250	18·24	2·74	11·7	16·8	205	263	
86	..	..	..	..	..	4780				13·6		242		
85·50	G = 15·5 mill.	..	..	..	..	4350				..		..		The combustible used was that known as "briquette."
85	..	..	..	..	..	4170				..		..		
84·50	..	..	..	..	..	4120				18·2		272		
84	..	..	..	..	..	4230				18·1		285		
83·50	..	..	..	..	..	4220				15·5		249		Pressure in the boiler, 9 atmospheres.
83	..	..	..	..	..	4210	..	..	..	17·9	..	280		


2806.
LUXEMBOURG
R = 4190k t = 102k
V = 17km·7 F = 275ch
(4020 × 182 + 4430 × 123)/305 = 419.
R = 4080k t = 95k
V = 19km F = 286ch
(4110 × 218 + 3920 × 68)/(218 + 68) = 408.
2807.
SPA
R = 4590k t = 118k
V = 15k·3 F = 258ch
(4430 × 153 + 4600 × 206)/359 = 459.

2603.

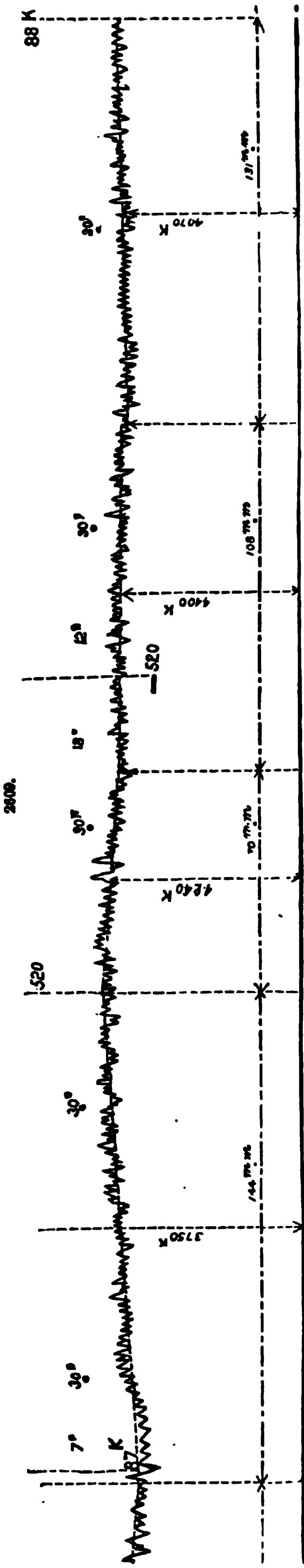


$B = 4280^k \quad V = 15^{km}\cdot 3$

$t = 118^k \quad F = 242^{ch}$

$$\frac{4380 \times 286 + 4000 \times 87}{373} = 428.$$

2609.



$B = 3700^k \quad V = 20^{km}\cdot 3$

$t = 85^k \quad F = 278^{ch}$

$$\frac{3640 \times 96 + 3750 \times 144}{240} = 370.$$

$B = 4110^k \quad V = 19^{km}\cdot 3$

$t = 97^k \quad F = 293^{ch}$

$$\frac{4240 \times 70 + 4100 \times 108 + 4070 \times 131}{70 + 108 + 131} = 411.$$

The forces, calculated as already described, are placed opposite the corresponding posts. When the nature of the line has been nearly constant throughout a long distance and the speed has varied but little, we may calculate,—

1. The mean force.
2. The mean speed.
3. The mean work of traction.

When the gross weight of the train is known, we may deduce the mean effective resistance a ton. In the foregoing Table which we give as an example, the mean effective resistance a ton is $18^{k}\cdot24$. The mean gradient was $15^{mm}\cdot50$; therefore, the mean resistance, corrected for gravity, is $2^{k}\cdot74$.

The trains which we experimented on were the ordinary daily trains, our object being to discover *usual* circumstances. From a purely technical point of view, it would no doubt have been much easier to make up special trains fulfilling such and such conditions of loading, of speed. or of lubrification, but this could not be realized in the ordinary work of a railway company.

The results have been collected into several Tables (Tables A to J). Tables A to E inclusive, relate to goods trains; Table F relates to mixed trains; and Tables G to J, to passenger trains. The total distance run during the experiments is;—

1360	kilomètres for	goods trains,
451	„	mixed trains,
1601	„	passenger trains,

which gives a gross total of 3412 kilomètres.

The total number of trains is 139, of which 54 were passenger trains, 9 mixed, and 76 goods trains.

Explanation of the Tables.—A Table similar to No. V. was drawn up for each train.

1. The column headed *Number of Kilomètres experimented over.*—The number of kilomètres in this column is 6 for train (E) 74, which is the last in Table E; this number corresponds to the bracketings in Table V., and not to the whole course of the train. We have thus omitted a certain fraction of the distance, which in some cases has been considerable. We cannot, in calculating the means, take into account those portions of the way which are very irregular, or where the speed has varied greatly. To obtain accuracy in calculations of this kind, the force of traction must have been continuous from one end of the given distance to the other, and nearly uniform. These conditions have been realized throughout the distances given in the column.

2. The column headed *Gross Weight of the Train.*—The gross weight of a train consists of two parts. The dead weight of the carriages, or non-paying load, and the paying load; the dead weight was obtained from the list of the tare, the paying load was given exactly by the guard's books.

3. The column headed *Nature of the Line.*—The incline is absolutely constant, or varies within narrow limits; in the latter case the number in the column is a mean.

4. The columns headed *Force of Traction, Force a Ton.*—The force of traction corresponds to the mean of the ordinates of the dynamometrical curve; the force f a ton, absolute or effective, is obtained by dividing the force of traction R by the gross weight of the train. If, however, there is a correction to be made, to take into account a positive or a negative acceleration (see Note A, later), the absolute force f a ton, though still deduced from the force of traction R, taken from the diagram, is not obtained in so simple a manner as before.

5. The column headed *Force a Ton, corrected.*—That is, after making the correction for gravity. We shall prove later that the coefficient of resistance upon an incline i is equal to $f+i$; that is, f being the resistance of the train a ton upon a level, if the train comes upon an incline i, without any change taking place in the speed or the conditions of traction, the resistance a ton upon the incline becomes $f+i$, i being the number of millimètres in the tangent of the inclination a mètre.

To eliminate the part played by gravity, and to render comparable trains tried upon different lines, or parts of a line, we have in each case subtracted i from the absolute resistance, so that the last column gives the values of f on a level.

With respect to Tables G to J we have only two special explanations to give;—

1. The weight of the paying load was found by adding to the weight of the luggage obtained from the guard's books, 70 kilogrammes a head for the passengers. This is not too much to include luggage in hand.

2. We have not confined ourselves, as we did in the case of goods trains, to calculating the resistance a ton; but we have calculated the resistance per carriage. It was comparatively easy to accomplish this, because the gross weight of the vehicle varies within much narrower limits in a passenger than in a goods train; in the former, the carriages being all covered, they are completely exposed to the resisting action of the air, and consequently absorb a nearly equal portion of the whole resistance of the train.

Goods Trains.—In reference to the experiments noted in Tables A to E, we have to make the following remarks;—

1. One or two engines were employed upon each train; there were two, three or four axles coupled to each engine, and the adhesive weight varied from 20 to 46 tons.

2. The gross weight of the trains varied from 152 to 571 tons; the number of trucks and vans was from 12 to 56, and of these some were empty, some partially, and others wholly loaded.

3. The proportion of trucks to vans varied from 0 to 97 per cent., and of these from 2 to 100 per cent. were lubricated with oil.

4. The inclination of the line varied between 1 and 20 in 1000; the minimum radius of the curves has been as low as 400 mètres.

5. The temperature was of all degrees -4 and $+26$ centigrade, and the weather was as varied as the temperature.

6. The mean speed fluctuated between 10 and 39 kilomètres an hour.

This for the data; as to the results, the following limits may be given;—

1. The force of traction has varied from 825 to 4690 kilogrammes (omitting the cases of double traction).

2. The absolute resistance a ton has varied from $2^{k}\cdot74$ to $22^{k}\cdot18$, according to the nature of the line.

3. The coefficient of resistance on a level has varied from $2^{k}\cdot21$ to $8^{k}\cdot60$, according to the speed and the state of the atmosphere.

Tables VI. and VII., which are taken from Tables A to E, bring together those trains that have been subject to the same circumstances of traction. Though, in these two Tables, the speed and the nature of the line were precisely the same, it will be seen that, in the second, the coefficients of resistance are greater than those of the former; this difference is due 1, to the smallness of the paying load, and 2, to atmospheric conditions (wind, frost, &c.).

In Table I. we have;—

For a speed of 17 to 26 kilomètres .. .. $f = 3^{k}\cdot15$
„ 26 to 32 „ .. .. $f = 3^{k}\cdot95$

which gives for a train in good condition of loading, mean weight a truck $\geqq$ 8000 kils. and for a mean ordinary speed, $f = 3^{k}\cdot55$ on a level.

TABLE VI.—GOODS TRAINS.

Designation of the Train.	Number of Trucks, &c.	Gross Weight Total.	Gross Weight a truck.	Temperature.	Proportion of Trucks to Vans.	Proportion of Trucks lubricated with Oil.	Speed an hour.	Resistance a ton, corrected for Gravity.	Observations.
		tons.	kilogs.	°	per cent.	per cent.	kiloms.	kils.	
199. June 20, 1862	53	567	10,700	+14	..	..	20	3·12	All these trains
62. Feb. 27, 1863	28	306	11,000	+13	14	43	25	3·14	have realized
‚0·62. April 28, 1864	60	509	8,500	+18	..	..	26	3·20	the following
66. Aug. 31, 1864	34	332	9,700	+18	25	11	17	3·14	conditions;—
							Mean	3·15	$i < 3$ mill.
567. June 27, 1862	27	221	8,200	+22	..	..	29	4·43	R $\geqq$ 1000 mèt.
562. June 15, 1862	33	301	9,100	+20	..	..	29	4·32	$t > 5°$.
64. March 19, 1863	29	321	11,100	+ 6	50	14	28	4·01	
62. Feb. 27, 1863	28	306	11,100	+13	14	43	31	3·18	The gross
78. March 17, 1864	46	474	10,300	+14	..	..	31	3·98	weight of the
88. March 18, 1864	26	249	9,500	+12	45	..	29	4·05	truck > 8000
78. April 12, 1864	28	300	10,700	+12	28	71	32	4·33	kilogrammes.
78. April 12, 1864	30	326	10,900	+18	30	71	29	3·54	Wind imper-
78. April 13, 1864	55	536	9,700	+19	36	..	31	4·41	ceptible.
78. April 13, 1864	55	536	9,700	+19	36	..	31	3·54	
66. Aug. 31, 1864	32	296	9,200	+19	25	11	30	3·74	
							Mean	3·95	
						General mean		3·55	

In Table VII. we find for this same mean ordinary speed;—

Calm weather, frosty, good paying load .. .. .. $f = 5^{k}\cdot09$
„ „ small paying load .. .. .. $f = 6^{k}\cdot26$
Windy, good paying load .. .. $f = 5^{k}\cdot06$
„ small paying load .. .. $f = 5^{k}\cdot87$
Calm weather, small paying load .. .. $f = 4^{k}\cdot87$

The smaller the paying load is, the greater is the number of axles for the same gross tonnage, and it is obvious that this fact must have great influence on the coefficient of traction, even if the line have no curves of a less radius than 1000 mètres.

Mixed Trains.—The following remarks apply to Table F;—

1. The number of engines employed on each train was one or two; the number of axles coupled, per engine, two or three; and the adhesive weight, 20 to 27 tons.

2. The gross weight of the trains varied from 120 to 239 tons; the number of carriages and trucks was from 14 to 30.

3. The proportion of open trucks was from 0 to 75 per cent., and of these 15 per cent. at the most were lubricated with oil.

4. The inclination of the line varied between the narrow limits of $0^{mm}\cdot4$ to $3^{mm}\cdot5$; the minimum radius of the curves was 1000 mètres.

5. The mean speed fluctuated between 25 and 52 kilomètres an hour. This latter speed, which is far above the ordinary, was attained only when it became necessary to recover lost time.

TABLE VII.—GOODS TRAINS.

Trains of difficult Traction from various causes.

Designation of the Train.	No. of Trucks &c.	Gross Weight Total.	Gross Weight a truck.	Atmospheric Conditions.	Proportion of Trucks to Vans.	Proportion of Trucks, &c., lubricated with Oil.	Speed an hour.	Resistance a ton, corrected.	Mean of the Coefficients.	Observations.
		tons.	kilogs.	°	per 100.	per 100.	kiloms.	kilogs.	kilogs.	
85. Feb. 22, 1863	37	281	7,600	Foggy calm T= −3	16	..	25	4·76		All the trains of this Table have
85. Feb. 22, 1863	37	281	7,600	„ T= −2	16	..	25	5·23	5·09	been subject to
88. Feb. 13, 1865	25	216	8,600	Calm T= −2	..	..	31	5·58		the following
88. Feb. 13, 1865	25	216	8,600	„ T= −2	..	..	33	4·80		conditions;—
61. Feb. 14, 1865	39	206	5,400	Calm T= −3	65	10	26	6·40		$i < 3$ mill.
75. Feb. 13, 1865	38	175	4,600	„ T= −3	80	25	33	7·27	6·26	$R \geqq 1000$ mèt.
85. Feb. 27, 1863	37	249	6,700	„ T= −2	30	3	25	4·88		
85. Feb. 27, 1863	39	267	6,800	„ T= −1	30	3	27	5·87		$V < 35$ kiloms.
91. April 13, 1864	40	338	8,400	Windy T=+ 7	..	..	28	4·78		To calculate the
91. April 13, 1864	40	338	8,400	„ T=+10	..	..	27	5·14		means in the
91. April 13, 1864	38	323	8,500	„ T=+10	..	..	26	5·92		last column we
91. April 13, 1864	38	323	8,500	„ T=+10	..	..	27	5·40	5·06	have taken only
91. April 13, 1864	38	323	8,500	„ T=+12	..	..	28	5·89		one coefficient
66. April 7, 1864	34	329	9,600	„ T=+12	60	..	24	4·68		a train, unless
78. March 17, 1864	47	478	10,200	„ T=+14	..	..	29	4·82		this train has
89. April 14, 1864	44	240	5,400	Windy T=+ 8	66	9	30	6·03		been subject to
89. April 14, 1864	44	240	5,400	„ T=+ 8	66	9	27	6·20		very varying
89. April 14, 1864	48	267	5,500	„ T=+10	66	9	20	7·73		conditions of
89. April 14, 1864	48	267	5,500	„ T=+10	66	9	27	7·60		traction, in
89. April 14, 1864	45	245	5,400	„ T=+10	66	9	26	7·46		which case several
89. April 14, 1864	45	245	5,400	„ T=+12	66	9	28	6·83		coefficients have
89. April 14, 1864	39	199	5,100	„ T=+18	66	9	31	7·90		been taken.
89. March 18, 1864	38	264	6,900	„ T=+11	30	8	28	4·79		
89. March 18, 1864	38	264	6,900	„ T=+11	30	8	18	5·94		
89. March 18, 1864	38	264	6,900	„ T=+11	30	8	26	5·92	5·87	
89. March 18, 1864	37	258	6,900	„ T=+11	30	8	32	6·15		
91. March 17, 1864	26	169	6,500	„ T=+ 5	..	..	24	6·93		
91. March 17, 1864	26	169	6,500	„ T=+ 5	..	..	25	7·68		
91. March 17, 1864	25	160	6,400	„ T=+ 8	..	..	30	7·87		
563. June 14, 1862	34	238	7,000	„ T=+15	..	..	24	4·55		
564. June 24, 1862	30	180	6,000	„ T=+18	..	..	24	5·06		
564. June 24, 1862	41	210	5,100	„ T=+18	..	..	20	5·16		
564. June 24, 1862	41	210	5,100	„ T=+18	..	..	28	6·45		
3/64. June 22, 1864	49	309	6,300	„ T=+18	50	..	24	4·82		
83. April 6, 1864	51	298	5,800	Calm	40	..	31	5·06		
3. April 6, 1864	44	244	5,500	„	40	..	26	4·93		
83. April 6, 1864	41	226	5,500	„	40	..	25	5·24		
77. Dec. 6, 1862	30	189	6,300	„ T=+12	18	..	32	5·20		
77. Dec. 6, 1862	28	172	6,100	„ T=+12	18	..	36	5·70		
562. June 25, 1862	28	196	7,000	„ T=+22	..	..	28	6·00		
81. April 11, 1864	43	254	5,900	„ T=+12	30	5	25	5·43		
81. April 11, 1864	43	254	5,900	„ T=+12	30	5	23	5·53		
81. Sept. 1, 1864	52	318	6,100	„ T=+25	40	7	29	3·74		
81. Sept. 1, 1864	49	299	6,100	„ T=+25	40	7	34	4·34		
75. Aug. 31, 1864	42	307	7,300	„ T=+20	14	7	20	4·19		
75. Aug. 31, 1864	42	307	7,300	„ T=+20	14	7	27	3·83	4·87	
75. Aug. 31, 1864	41	297	7,200	„ T=+20	14	7	14	4·15		
75. Aug. 31, 1864	40	273	6,800	„ T=+20	14	7	30	3·41		
75. Aug. 31, 1864	41	264	6,400	„ T=+20	14	7	21	4·54		
81. June 17, 1864	55	336	6,100	„ T=+21	27	..	17	3·22		
40/69. April 29, 1864	31	184	5,900		..	..	24	4·77		
83. March 16, 1864	29	196	6,700	Calm T=+ 6	31	7	22	5·00		
83. March 16, 1864	29	196	6,700	„ T=+ 6	31	7	26	5·14		
83. March 16, 1864	37	279	7,500	„ T=+ 9	25	5	33	4·12		
85. Nov. 26, 1862	33	207	6,200	„ T=+ 5	26	13	30	5·70		
85. Nov. 26, 1862	33	207	6,200	„ T=+ 5	26	13	26	6·00		
85. Nov. 26, 1862	33	207	6,200	„ T=+ 5	26	13	29	5·89		

Table VIII. gives those trains which were subject to the same circumstances of traction. Under good conditions of line, of load, and of weather, and with a mean speed of 34 to 44 kilomètres, these trains give a mean coefficient, $f = 4^k \cdot 67$, corresponding to the mean coefficient $f = 3^k \cdot 55$, found for goods trains at a mean speed of 20 to 30 kilomètres.

Fine weather, bad paying load .. .. $f = 5^k \cdot 48$
Windy, good paying load .. .. $f = 5^k \cdot 62$

Table VIII.—Mixed Trains. (Speed between 34 and 44 kilomètres.)

$i < 3$ millimètres. Radius of the curves $\geqq$ 1000 mètres. $t > 0°$.

Designation of the Train.	Number of Carriages.	Gross Weight: Total.	Gross Weight: a carriage.	Temperature.	Proportion of Trucks to Vans, &c.	Proportion of Trucks lubricated with Oil.	Speed an hour.	Resistance a ton, corrected.	bservations.
		tons.	kilogs.	°	per 100.		kiloms.	kils.	
100. April 25, 1862	24	239	9950	..	0	..	36	4·64	
100. April 25, 1862	25	227	9080	..	0	..	38	4·60	Gross weight of a truck, &c., > 8000 kilogs.
38. Dec. 5, 1862	22	200	9050	..	0	..	37	4·67	
38. Dec. 16, 1862	18	174	9650	+ 1	..	..	39	4·43	
46. Nov. 19, 1862	14	120	8550	+ 5	0	..	44	5·18	
							Mean	4·67	Fine weather.
100. April 16, 1862	28	207	7380	..	..	..	34	5·22	
100. April 16, 1862	25	190	7580	..	..	..	42	5·75	
							Mean	5·48	Light paying load. Fine weather.
100. Nov. 25, 1862	27	212	7850	+ 4	37	11	35	5·45	
100. Nov. 25, 1862	24	197	8200	+ 4	40	15	34	5·12	
100. Nov. 25, 1862	24	197	8200	+ 4	40	15	35	5·54	
46. Nov. 15, 1864	23	217	9450	+ 9	75	..	42	5·98	
46. Nov. 17, 1864	19	172	9050	+11	0	..	36	5·78	
46. Nov. 17, 1864	19	172	9050	+11	0	..	42	5·66	
							Mean	5·62	Windy. Good paying load.

Passenger Trains.—The following refers to Tables G to J;—

1. The number of engines employed was one or two to each train; the number of axles coupled, at the most, two per engine; and the adhesive weight was from 9800 to 22,000 kilogrammes.

2. The gross weight of the trains varied from 30 to 116 tons, and the number of carriages to a train was from five to twenty.

3. All the carriages were covered, the proportion of those lubricated with oil being from 7 to 50 per cent.

4. The inclination of the line varied from 0·75 to 10 millimètres, and the minimum radius of the curves was 700 mètres.

With respect to the results, we may state the following limits;—

1. The force of traction has varied from 505 to 1400 kilogrammes for a single engine.

2. The absolute force per carriage has varied from 32 to 131 kilogrammes, and the absolute force a ton from $5^k \cdot 08$ to $20^k \cdot 39$.

3. The force corrected for gravity has varied;—

A carriage .. .. from 21 to 131 kilogrammes.
A ton .. .. from 3·75 to 20·26 „

Table IX. gives the coefficients for long trains. The number of carriages was from fourteen to seventeen. The following is the value of the mean coefficients;—

For $V = 45^k$ .. .. $f = 5^k \cdot 98$
„ $V = 52^k$ .. .. $f = 6^k \cdot 53$
„ $V = 60^k$ .. .. $f = 8^k \cdot 05$

Table X. is for short trains. The number of carriages was eight to ten. The following is the value of the mean coefficients;—

For $V = 46^k$ .. .. $f = 7^k \cdot 21$
„ $V = 58^k$ .. .. $f = 9^k \cdot 57$
„ $V = 76^k$ .. .. $f = 14^k \cdot 55$

The last coefficient is for an express train, the carriages of which offer a greater surface to the air than those of ordinary trains. This cause combined with the increased speed to augment the coefficient.

TABLE IX.—PASSENGER TRAINS.

$i < 3$ millimètres. $R \overset{=}{>} 1000$ mètres. $t > 0°$. $n > 10$. Calm weather.

Designation of the Train.	Number of Carriages.	Gross Weight.	Proportion of Carriages lubricated with Oil.	Temperature.	Speed an hour.	Mean of the Speeds.	Resistance a ton on a Level.	Mean of the Resistances.	Mean Resistance a carriage.	Mean of the Resistances a carriage.
		tons.	per 100.	°	kiloms.	kiloms.	kils.	kils.	kils.	kils.
35. April 27, 1862	14	90	..	+14	47	45	6·24	5·98	40	37
36. May 26, 1862	17	101	..	22	46		5·54		33	
40·26. April 28, 1866	17	101	30	20	44		6·43		38	
44. June 8, 1866	17	107	17	25	45		5·73		36	
35. April 27, 1862	14	90	..	14	54	52	6·95	6·53	44	40
35. May 1, 1862	16	101	..	..	50		6·03		38	
36. May 6, 1862	17	101	..	22	54		6·03		35	
35. May 7, 1862	16	106	..	17	50		6·71		44	
40·23. April 28, 1866	17	101	30	24	52		6·54		38	
35. June 4, 1866	17	105	..	19	54		6·95		43	
36. April 30, 1862	15	91	..	..	58	60	8·03	8·05	49	48
35. Nov. 19, 1864	17	98	..	8	59		7·95		45	
35. June 4, 1866	17	105	..	19	63		8·16		50	

TABLE X.—PASSENGER TRAINS.

$i > 3$ millimètres. $R \overset{=}{>} 1000$ mètres. $t > 0°$. $n \overset{=}{>} 10$. Calm weather.

Designation of the Train.	Number of Carriages.	Gross Weight.	Proportion of Carriages lubricated with Oil.	Temperature.	Speed an hour.	Mean of the Speeds.	Resistance a ton on a Level.	Mean of the Resistances.	Mean Resistance a carriage.	Mean of the Resistances.
		tons.	per 100.	°	kiloms.	kiloms.	kils.	kils.	kils.	kils.
40·35. April 24, 1866	8	50	25	+17	45	46	7·44	7·21	45	44
40·35. April 26, 1866	9	56	44	20	41		7·27		45	
2·16. June 6, 1866	10	58	30	23	46		7·56		44	
2·16. June 7, 1866	10	62	30	27	51		6·59		41	
40·35. April 24, 1866	8	50	25	17	65	58	9·80	9·57	58	58
40·32. April 25, 1866	9	55	33	15	60		9·80		55	
2·16. June 5, 1866	10	61	10	23	61		9·80		60	
33. March 14, 1866	8	53	..	2	76	76	14·55	14·55	96	96

TABLE XI.—PASSENGER TRAINS.

Trains of difficult Traction from various causes.

Designation of the Train.	Number of Carriages.	Gross Weight.	Atmospheric Circumstances.	Proportion of Carriages lubricated with Oil.	Speed an hour.	Resistance corrected: a ton.	Resistance corrected: a carriage.	Observations.
		tons.		per 100.	kiloms.	kils.	kils.	
31. Dec. 21, 1865	12	65	T = + 5°	..	55	11·80	66	All the trains of this Table have been subject to the following conditions;—
31. Dec. 21, 1865	12	65	T = + 5°	..	48	11·40	66	$i < 3$ millimètres.
32. March 12, 1866	12	79	Dry; a little wind; T = + 8°	33	51	9·55	63	$R \overset{=}{>} 100$ mètres.
32. March 15, 1866	12	72	Dry; a little wind; T + = 8°	25	43	11·40	68	$t > 0°$.
36. Dec. 10, 1862	20	72	Wind and wet; T = + 7°	..	43	9·35	54	$n > 10°$.
20. Aug. 3, 1866	12	116	A little wind; dry; T = + 24°	42	45	10·19	61	
40·35. April 24, 1866	12	73	Windy and dry; T = + 17°	17	45	12·21	71	
				Means	47	10·84	64	

Passenger Trains of Difficult Traction.—In Table XI. we have brought together several trains which offered extraordinary difficulties with regard to traction, either on account of the wind, or of very imperfect lubrication of the parts liable to friction. This Table applies to trains having more than ten carriages; it gives the mean coefficient of $10^{k} \cdot 84$ for a mean speed of 47 kilomètres an hour. The three Tables, IX., X., and XI., have been extracted from the general Tables.

Resistance of Trains at Starting.—Hitherto we have been considering the resistance of trains in motion; we have now to consider the resistance offered at starting. In this case, the greatest force exerted by the engine upon the couplings to overcome the inertia of the train corresponds to the greatest ordinate given by the dynamometrical curve. Tables XII. and XIII. contain the results of a large number of experiments made with both passenger and goods trains.

TABLE XII.—RESISTANCE OF PASSENGER TRAINS AT STARTING.

Designation of the Train.	Gross Weight.	Number of Carriages.	Proportion of Carriages lubricated with Oil.	Temperature.	Force necessary to put the Train in motion			Observations.
					Total.	a ton.	a carriage.	
	tons.		per 100.	°	kils.	kils.	kils.	
17. April 11, 1864	52	10	..	+15	1230	24	123	
34. April 27, 1864	63	11	..	+13	1150	18	104	
35. Nov. 17, 1864	82	14	..	+ 8	2000	24	143	
31. Nov. 21, 1864	85	18	..	+ 8	1920	23	107	
31. May 4, 1865	70	12	8	+27	1880	26	156	
2·16. July 20, 1865	78	12	..	+20	1850	24	154	
1·43. July 19, 1865	64	10	10	+17	1140	18	114	Engines with free wheels.
2·43. July 19, 1865	83	13	..	+17	1580	19	121	
2·16. July 21, 1865	97	15	7	+20	1960	20	130	
2·43. July 21, 1865	77	13	15	+20	1810	24	139	
1·38. July 21, 1865	40	7	..	..	1160	29	166	Ditto.
31. Dec. 21, 1865	73	14	..	+ 5	2150	29	153	
32. March 12, 1866	79	12	33	+ 8	1840	23	153	
33. March 13, 1866	52	8	..	+ 6	1080	21	135	Ditto.
32. March 13, 1866	88	14	28	+ 7	1730	20	124	
33. March 14, 1866	53	8	..	+ 2	1090	21	136	Ditto.
32. March 14, 1866	78	12	25	+ 6	1280	16	106	
33. March 15, 1866	52	8	..	+ 2	1350	26	169	Ditto.
32. March 15, 1866	72	12	25	+ 8	1900	26	158	
40·35. April 24, 1866	70	12	16	+17	1700	24	141	
40·32. April 25, 1866	55	9	33	+15	1320	24	147	
40·35. April 26, 1866	56	9	44	+20	1200	21	133	The mean a ton is = 22; the mean a carriage = 134.
40·34. April 27, 1866	81	14	20	+26	2100	26	150	
40·23. April 28, 1866	101	17	30	+24	1800	18	105	
41·26. April 28, 1866	67	11	..	+20	1320	20	120	
40·26. April 28, 1866	101	17	30	+20	1650	16	97	
35. June 4, 1866	105	17	..	+19	1650	16	97	
2·13. June 5, 1866	49	9	11	+20	1500	30	166	
2·16. June 5, 1866	61	10	10	+23	1700	28	170	
2·43. June 6, 1866	68	11	9	+18	1430	21	130	
2·16. June 6, 1866	58	10	30	+23	1330	23	133	
1·16. June 7, 1866	53	10	10	+25	1750	33	175	
44. June 8, 1866	107	17	17	+25	2000	17	117	Engines with free wheels.

Note.—The line is level, or inclined less than 1 millimètre.

It will be seen from Table XIII. that the mean force required was 13 kilogrammes a ton. For very long trains, a force of 8, and in some cases 6, kilogrammes only was sufficient to put the train in motion, a circumstance which is explained by the fact that the carriages of a train start each in succession, and not simultaneously. The mean force requisite for passenger trains was 22 kilogrammes a ton, or about 134 kilogrammes a carriage. It must be remembered that these figures refer only to instances when the start has been gently accomplished; when the train is put in motion in an abrupt manner a considerably greater force is exerted.

Generally, it may be stated that passenger trains require a force nearly twice as great as that necessary for goods trains. The causes of this are the tight coupling of the former, and the necessity of getting the train sooner into rapid motion.

Analysis of the Resistance of Engines.—A series of experiments were undertaken to determine separately the portion of the whole resistance due—

1. To the rolling of engines considered as mere vehicles;
2. To the friction of the side connecting-rods;
3. To the friction of the pistons, connecting-rods, and cross-heads.

TABLE XIII.—RESISTANCE OF GOODS TRAINS AT STARTING.

Designation of the Train.	Gross Weight.	No. of Trucks, &c.	Proportion of Trucks lubricated with Oil.	Temperature.	Force required to put the Train in motion		Observations.
					Total.	a ton.	
	tons.		per 100.	°	kils.	kils.	
91. March 17, 1864	160	25	..	+ 2	2800	11	
78. March 17, 1864	478	47	..	+14	5220	11	Double traction.
88. March 18, 1864	241	29	..	+12	3270	11	
89. March 18, 1864	264	38	8	+11	3560	13	
83. April 6, 1864	302	51	..	..	4020	13	
81. April 11, 1864	254	43	5	+12	3880	15	
78. April 12, 1864	300	28	3	+12	3740	13	
91. April 13, 1864	338	40	..	+ 7	3550	10	
78. April 13, 1864	534	55	..	+19	6600	12	Double traction.
89. April 14, 1864	267	48	9	+ 8	3720	14	
88. April 14, 1864	322	38	..	+19	4620	14	
40·69. April 28, 1864	278	35	8	+20	3340	12	
66. April 15, 1864	264	29	..	+20	3500	13	
40·62. April 28, 1864	511	60	..	+18	3160	6	Double traction.
40·69. April 29, 1864	184	31	..	..	3090	17	
81. June 17, 1864	336	55	..	+21	4400	13	
1·67. June 20, 1864	334	46	11	..	5550	17	
1·68. June 20, 1864	245	32	8	..	3060	12	
1·68. June 21, 1864	304	33	15	..	3750	12	
1·64. June 22, 1864	298	45	..	..	4800	16	
1·67. July 6, 1864	269	41	12	+16	3040	11	
1·70. July 7, 1864	362	30	13	..	4100	15	
1·68. July 8, 1864	295	29	6	..	4340	14	
1·67. July 26, 1864	170	28	15	..	3020	18	
75. Aug. 31, 1864	297	41	7	+20	2880	10	
66. Aug. 31, 1864	332	34	25	..	3150	10	
81. Sept. 1, 1864	315	52	7	+25	2620	8	Engine, type 20.
75. Feb. 13, 1865	175	38	25	− 3	2390	14	
61. Feb. 14, 1865	206	39	10	− 3	2540	12	
78. Feb. 14, 1865	185	22	10	− 1	3060	16	
2·65. July 20, 1865	255	35	20	+20	3250	13	
2·65. July 21, 1865	259	39	30	+25	3440	13	
74. Jan. 9, 1867	370	41	..	..	4080	11	
1·64. Jan. 14, 1867	204	21	..	..	3620	18	
					Mean ..	13	

Note.—The line is level, or inclined less than 1 millimètre.

To accomplish this, an engine having its steam up and being properly oiled was drawn, *without a tender*, behind the dynamometer car.

The results of these experiments are given in Table XIV.

1. For a mixed engine in full gear, but without tender,

$$V = 28^{k} \quad .. \; .. \; .. \; .. \; .. \; .. \; .. \; .. \quad f = 9^{k}\cdot 60$$

For a goods engine in full gear, but without tender,

$$V = 28^{k} \quad .. \; .. \; .. \; .. \; .. \; .. \; .. \; .. \quad f = 12^{k}\cdot 20$$

2. It is impossible to draw any conclusion from the reduction of the resistance due to the suppression of the side connecting-rods; and, indeed, we see that the resistance has been greater on several occasions when the side connecting-rods were suppressed than when the engine was in full gear. The difference in these cases must be attributed to the condition of the lubricated parts. But a great influence from the connection of the wheels was not to be expected, seeing that the experiments were made on a straight piece of line, and that the tire was very round.

3. The influence of the pistons, connecting-rods, and cross-heads was, however, clearly shown. For mixed or goods engines, the resistance of these parts is about 48 per cent. of the whole resistance of the engine in full gear.

It must be remembered that these results refer only to engines which are not working. If the engine is at work, its parts are subject to totally different pressures, and the resistance is changed in a like degree. (See Notes D and H.)

From Table XIV. we find the resistance of engines reduced to the condition of mere vehicles by putting out of gear the driving and side connecting-rods. The mean of this resistance is $5^{k}\cdot 22$ for mixed engines at a speed of 28 to 35 kilomètres, and $6^{k}\cdot 15$ for goods engines at a speed of 24 to 27 kilomètres. For engines with four axles coupled (out of gear), at a speed of 6 to 10 kilomètres, we find $f = 11$ kilogrammes.

In this kind of engine the resistance due to the mechanism is also about half the total resistance. These powerful engines when moving at a low rate of speed offer a resistance much greater

TABLE XIV.—EXPERIMENTS ON THE RESISTANCE OF ENGINES IN MOTION (without Tender).

Kind of Engine.	Number of the Engine.	Weight of the Engine.	Condition of the Mechanism.	Number of Kilomètres experimented over.	Speed an hour.	Mean total Resistance.	Mean Resistance a ton.	Fraction by which the Resistance is diminished when the Mechanism is out of gear.	Observations.
		kilogs.			kiloms.	kilogs.	kilogs.	per 100.	
Mixed.—Type 14. Four wheels coupled. D = 1m·68.	247	31,300	Heated, in full gear	6	27	300	9·58	..	
			Connecting-rods out of gear	6	26	135	4·32	55	
		30,700	Side connecting-rods out of gear	8	32	267	8·69	11	
			Connecting and side connecting rods out of gear .	5	28	139	4·52	54	
		31,300	Heated, in full gear	5	44	319	10·19	..	
			Connecting-rods out of gear	7	38	141	4·50	56	
		30,700	Side connecting-rods out of gear	6	44	326	10·61	..	
			Connecting and side connecting rods out of gear .	5	35	159	5·18	50	
	249	31,700	Heated, in full gear	5	30	305	9·63	..	
			Connecting-rods out of gear	5	26	182	5·70	40	
		31,400	Side connecting-rods out of gear	13	30	456	14·60	..	Engine cold, imperfect state of lubrication.
			Connecting and side connecting rods out of gear .	5	28	176	5·60	42	
		31,700	Heated, in full gear	7	45	374	11·80	..	
			Connecting-rods out of gear	5	36	193	6·09	48	
		31,400	Connecting and side connecting rods out of gear .	4	45	207	6·58	44	
	0·123	29,700	Heated, in full gear	12	27	370	12·40	..	
Goods.—Type 15. Six wheels coupled. D = 1m·30.	0·154	30,000	Connecting-rods out of gear	12	27	192	6·46	48	
			Side connecting-rods out of gear	12	26	405	13·60	..	Engine cold, imperfect state of lubrication.
			Connecting and side connecting rods out of gear .	12	27	190	6·35	48	
			Heated, in full gear	12	29	360	12·00	..	
			Connecting-rods out of gear	10	27	200	6·66	44	
			Side connecting-rods out of gear	13	27	324	10·80	10	
			Connecting and side connecting rods out of gear .	10	24	179	5·96	50	

than that of other engines, because there is in their mechanism a larger surface subject to friction, the weight of their parts is greater, and their wheels are smaller.

Causes which may Influence the Coefficients of Resistance in Carriages.—As we did in the case of engines, so in the case of carriages we have endeavoured to discover the various causes which may influence the coefficients of resistance. On a level, and in a straight line, this resistance is composed of two elements;—

1. The friction of the wheels;
2. The resistance due to the atmosphere.

If the rate of speed is very low, the second element disappears.

Neglecting, therefore, the resistance due to the atmosphere, we have considered the influence of lubrication, of the diameter of the journals, and of the extent of the surface subject to friction.

Making R the resistance of a vehicle;
p its weight, minus the wheels;
p' the weight of the wheels;
d the diameter of the journals;
D the diameter of the wheels;
f' the coefficient of rolling at the circumference;
f'' the coefficient of the friction of the journal upon its bearings;

we have

$$R = (p + p')f' + pf'' \times \frac{d}{D}. \qquad [E]$$

Friction in an Oil-box.—In the Table of the mean resistance of the carriage moving at different velocities, we saw that for a covered carriage lubricated with oil, the mean resistance R = 11 kilogrammes ($p + p' = 5500$ kilogrammes), at a speed of 1 to 5 kilomètres.

At this rate of speed, the resistance of the air may be neglected, and we may state

$$11 = 5500 \times 0\cdot001 + 3900 \times 0\cdot075 f''. \qquad [E]$$

(In the rolling stock of the Eastern Company, upon whose line the experiments were made, D = 1 mètre, $d = 0^{m}\cdot075$, and f' is admitted to be $= 0\cdot001$.)

From [E] we deduce $f'' = 0\cdot018$.

This is the coefficient of friction in an oil-box, where the lubrication is continuous, at a low rate of speed.

Friction in a Grease-box.—From the special experiments made in 1862, the mean of the ratios between the traction of a carriage lubricated with oil and that of a carriage lubricated with grease was found to be 1·35.

Equation [E] therefore becomes $11 \times 1\cdot35 = 5500 \times 0\cdot001 + 3900 \times 0\cdot075 f''$; when we deduce $f'' = 0\cdot032$.

Friction for a Whole Train.—Taking, in our experiments, trains made up chiefly of carriages lubricated with oil, and moving at a rate of speed not exceeding 20 kilomètres, the results obtained were the following;—

($f' = 0\cdot001$.)

Experiment No.	189,	$f = 2^{k}\cdot7$,	whence	$f'' = 0\cdot026$
"	188,	$f = 2^{k}\cdot4$,	"	$f'' = 0\cdot021$
"	166,	$f = 2^{k}\cdot7$,	"	$f'' = 0\cdot026$
"	167,	$f = 2^{k}\cdot6$,	"	$f'' = 0\cdot025$
"	169,	$f = 2^{k}\cdot3$,	"	$f'' = 0\cdot020$
"	172,	$f = 2^{k}\cdot2$,	"	$f'' = 0\cdot019$

For a train having only 10 per cent. of carriages lubricated with oil, we have

Experiment No. 99, $f = 3^{k}\cdot1$, whence $f'' = 0\ 034$.

f'', the friction of the journals, is calculated by means of equation [E], in which $B = f \times G$; G being the gross weight of a carriage expressed in tons.

Influence of the Load upon the Friction of the Journals.—The mean gross weight of the carriages on which the experiments were made differed widely, yet the coefficients f'' remained nearly the same, from which we conclude that the friction of the journals is independent of the load, so long as the wheels turn freely, and the influence of curves and of the atmosphere is absent.

Friction in the Boxes of a Tender.—For a tender weighing 19,000 kilogrammes, moving at a speed of 25 to 30 kilomètres, it was found that $f'' = 0\cdot043$. (Grease-boxes.)

Friction in the Boxes of an Engine.—For an engine of the types 14 and 15, weighing 30,000 kilogrammes, at a speed of 25 to 30 kilomètres, $f'' = 0\ 052$. (Lubricated with oil, and the mechanism out of gear.)

Pressure a Square Centimètre of Surface subject to Friction.—Calculating the pressure from the foregoing figures, we find

For carriages loaded with 10 tons	$17^{k}\cdot90$
" engines	$13^{k}\cdot20$
" a carriage loaded with 5 tons	$11^{k}\cdot90$

Influence of the Extent of Surface on the Friction of the Journals.—For carriages, the mean surface subject to friction is, per journal, 188 square centimètres: for engines (types 14 and 15) it is 452 centimètres, there is, therefore, in this respect, a great difference between carriages and engines.

Now, for carriages, we found	$f'' = 0\cdot018$
And for engines	$f'' = 0\cdot053$

The ratio of these coefficients gives $\frac{18}{53} = 0 \cdot 33$. The same value is obtained by raising the ratio of the surfaces to the power $\frac{4}{3}$. There is, therefore, an advantage, from the point of view of traction, in reducing to its minimum the surface subject to friction; taking care, of course, that the journals have sufficient dimensions to prevent their breaking, and to allow the wheels to turn freely.

This double consideration, the reduction of the dimensions and the resistance of the journals, has led to the construction of cast-steel axles. The results have, however, not been satisfactory; cast steel is brittle; Bessemer steel which is softer than cast steel, and of greater resisting power than iron, would no doubt offer greater advantages.

Friction on the Journals of Carriages at Starting.—We have already seen that the resistance of a carriage lubricated with oil, is at starting 48 kilogrammes ($8^k \cdot 70$ a ton). The equation thus gives $f'' = 0 \cdot 145$ for the friction of the journals at starting. Experiments have shown us (Table XIII.) that this coefficient is nearly the same when the lubrication is effected by means of grease. Until the train has moved a distance of some 50 mètres, the advantage of oil is not apparent, especially if the temperature is much above 0°. This is no doubt owing to the fluidity of the oil which in some degree runs from the surfaces subject to friction while the train is stationary.

TABLE XV.—FRICTION ON THE JOURNALS OF CARRIAGES.

$R \lesseqgtr 1000$ mètres. $T > 10°$; no wind.

Number of the Experiment.	Proportion of Carriages lubricated with Oil.	Speed an hour.	Coefficient of the total Friction.	Coefficient of the Friction on the Journals.	Gross Weight a carriage.
	per 100.	kiloms.			kilogs.
No. 3, Table A	..	19	0·0031	0·035	8,250
" 10 " A	..	20	0·0031	0·032	10,700
" 40 " B	..	25	0·0031	0·033	10,900
" 42 " B	..	31	0·0029	0·030	10,730
" 59 " B	..	33	0·0034	0·038	10,300
" 99 " C	..	22	0·0031	0·034	9,420
" 100 " C	8	23	0·0030	0·033	7,950
" 102 " C	..	26	0·0032	0·036	8,480
" 103 " C	..	17	0·0028	0·033	5,940
" 105 " C	..	17	0·0032	0·039	6,120
" 106 " C	..	10	0·0029	0·035	6,030
" 115 " D	..	19	0·0031	0·036	6,280
" 139 " D	..	15	0·0033	0·038	7,900
" 150 " D	11	17	0·0031	0·033	9,750
" 152 " D	11	19	0·0026	0·026	9,420
" 154 " E	7	15	0·0031	0·037	6,300
" 156 " E	7	16	0·0031	0·038	5,920
" 163 " E	20	15	0·0031	0·036	7,250
	Means ..	20	0·0031	0·035	..

Influence of the Temperature on the Resistance.—In the case of trains lubricated with oil, the influence of the temperature is not appreciable. The advantage possessed by oil over grease, to which we have already called attention, is for a moderate temperature; in winter this advantage is greater. The addition of a small quantity of petroleum to the ordinary oil prevents congealation in the lowest temperature to which our climate is liable.

Table XVI. shows the influence of temperature on the resistance of trains lubricated with grease; it divides into two series, trains having only 10 per cent. of oil-boxes and offering the same circumstances of line, load and speed, in calm weather.

1st series. Temperature from 0° to 3° .. .. .. $f = 5 \cdot 22$
2nd series. " 15° to 20° .. .. .. $f = 3 \cdot 47$

For low temperatures the increase is 50 per cent.

2610.

Influence of Inclines on the Resistance.—The equation [E] supposes the line to be straight and level; for an incline, making an angle a with the horizon, it becomes

$$R = \cos. a \left((p + p') f' + p f'' \frac{d}{D} \right) + (p + p') \sin. a.$$

Within the limits of inclines existing on railways, cos. a differs but little from unity, and sin. a may be replaced by tan. a, Fig. 2610. Putting i for the value of tan. a, in millimètres, we have as the resistance of a carriage moving in a straight line and on an incline,

$$R = (p + p')\, f' + p f'' \frac{d}{D} + (p + p')\, i, \qquad [F]$$

or $$R = (p + p')\, f + (p + p')\, i.$$

TABLE XVI.—INFLUENCE OF FROST.

Wind, hardly perceptible. Speed, 25 kilomètres an hour.

Number of the Experiment.	Proportion of Carriages lubricated with Oil.	Temperature.	Least Radius of the Curves.	Gross Weight a carriage.	Speed an hour.	Coefficient of Traction.	Observations.
	per 100.	°	mètres.	kilogs.	kiloms.	kilogs.	
36	3	− 2	1500	6730	25	4·88	It will be seen that these two series of trains have, with the exception of temperature, been subject to similar conditions.
37	3	− 1	1000	6850	27	5·37	
43	about 10	− 3	straight	7600	26	4·69	
44	" 10	− 3	1500	7600	25	4·76	
45	" 10	− 2	1000	7600	25	5·23	
160	" 10	− 3	straight	5280	26	6·40	
			Means ..	6940	26	5·22	
100	8	+ 20	1200	7950	23	3·04	
115	about 10	at least 15	at least 1000	6280	19	3·12	
140	" 10	+ 15	straight	7920	23	3·76	
144	7	+ 20	2000	7280	27	3·83	
114	about 10	at least 15	at least 1000	6350	26	3·70	
146	7	+ 20	1000	6820	30	3·41	
			Means ..	7100	25	3·47	

Former experiments showed R to be considerably less than the value given by the equation [F]. The results of our labours enable us to assert that this equation is rigorously exact.

Table XVII., which is made up of trains subject to the same conditions of loading, lubrication, curves, and atmosphere, places the matter beyond a doubt.

Table XVII.—1st series. Mean inclination, $1^{mm}\cdot46$; we have $f = 3\cdot18$
2nd " " $4^{mm}\cdot44$ " $f = 2\cdot97$
3rd " " $9^{mm}\cdot50$ " $f = 3\cdot25$

The value of f was calculated by the equations [F], R being given by experiment. It will be seen that the coefficient of resistance does not decrease when the inclination increases.

4th series. Mean inclination, $5^{mm}\cdot18$; we have $f = 3\cdot39$
5th " " $9^{mm}\cdot25$ " $f = 3\cdot96$

We find rather an increase for the greater incline.

6th series. Mean inclination, $16^{mm}\cdot79$; we have $f = 2\cdot56$
7th " " $2^{mm}\cdot05$ " $f = 3\cdot40$

But here we must remark that the trains of the 7th series were furnished with fewer oil-boxes, that they were twice the length, and moved at twice the speed of those of the 6th series.

We may therefore conclude that, upon an incline, the coefficient of resistance a ton is found by adding to the coefficient on a level, obtained under the same circumstances, as many kilogrammes as there are thousandths in the inclination.

This law is rigorously true, and if the conclusions of some who have considered the subject have been opposed to it, it is probably because they have not made their experiments under identical circumstances of speed and length of train.

Influence of the Length of a Train on the Resistance.—In passenger trains moving at rates of speed greater than 40 kilomètres an hour, the resistance of the air forms an important part of the whole resistance. The action of the air is greater upon the first carriage than upon the others, whence it follows that the resistance per carriage decreases as the length of the train increases. This fact is verified in Tables IX. and X. When the radii of the curves are much below 1000 mètres, this law will not hold good, because the influence of the air will be destroyed by that of the curve.

The length of goods trains may vary within much wider limits than those imposed on passenger trains. In a straight line, or on a curve of a very long radius, the length has no appreciable influence. And, as a fact, it was found that the coefficients for trains of 50 or 60 trucks were very small. But if the radius of the curve is less than 1000 mètres, an increase of length causes an increase of resistance. It must be remembered that in this case the resistance of the air is not the only retarding force to be considered. There is an additional friction on the tire, caused by the direction of the force of traction not coinciding with the axis of the carriages.

Influence of Curves on the Resistance.—The gauge, or normal breadth of the line on the *Chemin de fer de l'Est* is fixed at $1^{m}\cdot447$ of clear space between the rails. This allows a carriage-axle to run upon a curve having a radius of 444 mètres, without sliding or friction of the flanges. In the case of passenger trains composed of 10 to 20 carriages and moving at a rate of speed of 35 to 50 kilomètres an hour, we were unable to discover the smallest influence. It is true that the shortest radii of the curves on which our experiments were made were of 800 mètres. At a rate of speed exceeding 50 kilomètres, the influence of the curve became apparent. In train 31, Table H, experiments 60 and 61, this influence was 5 per 100.

TABLE XVII.—INFLUENCE OF INCLINES ON THE COEFFICIENT OF RESISTANCE.

Speed, 15 to 25 kilomètres an hour. Wind, hardly perceptible.

Number of the Experiment.	Inclination of the Line.	Radius of the Curves.	Speed an hour.	Number of Carriages.	Proportion of Carriages lubricated with Oil.	Absolute Force a ton.	Force a ton, corrected.	Observations.
	millimètres.	mètres.	kiloms.		per 100.	kilogs.	kilogs.	
105	0·43	1000	17	55	..	3·65	3·22	First series.
150	2·50		17	34	11	5·64	3·14	
Mean ..	1·46	1000	17	44	..	4·64	3·18	
154	3·50	1000	15	51	7	6·65	3·15	Second series.
152	3·50		19	32	11	6·15	2·65	
3	6·00		19	26	..	9·10	3·10	
103	5·70		17	31	..	8·55	2·85	
106	3·50		10	54	..	6·45	2·95	
115	4·50		19	49	..	7·82	3·12	
Mean ..	4·44	1000	16	41	..	7·47	2·97	
139	9·00	1000	15	40	..	12·35	3·35	Third series.
163	10·00		15	35	20	13·15	3·15	
Mean ..	9·50	1000	15	38	..	17·75	3·25	
111	5·70	700 to 800	20	36	8	9·87	4·17	Fourth series.
113	5·66		17	32	8	10·18	4·47	
134	5·70		15	35	6	9·44	3·74	
138	5·66		20	31	..	9·00	3·34	
165	4·42		17	38	76	7·65	2·23	
167	5·00		13	38	70	7·56	2·56	
168	4·84		19	35	50	7·85	3·01	
176	4·80		17	44	36	7·55	2·75	
181	5·00		16	40	30	8·56	3·56	
177	5·00		16	44	36	8·05	3·05	
Mean ..	5·18	7 to 800	17	37	..	8·57	3·39	
107	9·25	700 to 800	20	46	11	13·45	4·20	Fifth series.
137	9·25		15	28	18	13·72	4·47	
184–185	9·25		16	33	42	12·47	3·22	
Mean ..	9·25	7 to 800	17	36	..	13·21	3·96	
186	15·00	400 to 600	16	12	66	17·60	2·60	Sixth series.
187	16·89		12	12	66	19·42	2·53	
188	19·80		10	12	66	22·18	2·38	
189	15·50		17	16	100	18·24	2·74	
Mean ..	16·79	4 to 600	14	13	74	19·35	2·56	
123	2·40	400 to 600	25	30	13	5·58	3·18	Seventh series.
124	1·40		29	30	13	5·23	3·83	
125	3·50		21	30	13	7·10	3·60	
126	0·90		21	30	13	3·90	3·00	
Mean ..	2·05	4 to 600	26	30	13	5·45	3·40	

Table XVIII. shows the influence of curves upon goods trains. The mean speed (20 to 30 kilomètres) and the mean number of vehicles (26 to 56) were about the same for the different trains. The following are the results;—

1. When the length of the curves met with in a given distance is less than 20 per 100 $f = 4^{k}\cdot43$
2. When the length of the curves in the given distance is between 20 and 50 per 100 $f = 4^{k}\cdot76$
3. When the length of the curves is greater than 50 per 100 .. .. $f = 5^{k}\cdot12$

We have considered the line as straight when the radius of the curve has been greater than 2000 mètres. The radii of the other curves were between 1000 and 2000 mètres. It is shown, therefore, that curves of a long radius exert a sensible influence upon goods trains.

Our experiments have shown us that if we denote the coefficient of resistance a ton in a straight line by f,

The coefficient on a curve of 1000 mètres will be .. .. .. $f + 1$
And " " 800 " .. .. .. $f + 1 \cdot 50$

Influence of the Condition of the Permanent Way upon the Resistance.—The rails upon which the greater part of our experiments were made are 6 mètres in length, and the joints are covered with plates. When the condition of the permanent way is not good, when, for example, it is near the time for repairs, the train is subject to more or less violent shocks according to the rate of speed. A case of this kind occurred to the express trains No. 33 of the 13th to the 16th March, 1865, Paris to Strasbourg. The way was in a bad state from the kilomètre-post 96 to post 115. Comparing the force and the speed on this section of the line with the force and speed in an adjoining section which was in a good condition, offering the same circumstance of curve, *viz.* from post 74 to post 84, we find for the way in a bad condition;—

1. Train 33, March 13, for $V = 67^k$ .. .. .. $f = 112^k$
2. " " 14, for $V = 59^k$ .. .. .. $f = 100^k$
3. " " 15, for $V = 67^k$ .. .. .. $f = 125^k$

Mean .. .. $V = 64^k$ and $f = 112^k$ a carriage.

And for the way in a good condition;—

1. Train 33, March 13, for $V = 72^k$ .. .. .. $f = 115^k$
2. " " 14, for $V = 75^k$ .. .. .. $f = 95^k$
3. " " 15, for $V = 77^k$ .. .. .. $f = 132^k$

Mean .. .. $V = 75^k$ and $f = 114^k$ a carriage.

Thus, it may be stated that, on account of the bad condition of the permanent way, the speed was reduced from 75 to 64 kilomètres without any reduction of force. The increased resistance was due to shocks and a certain amount of friction on the flanges.

Influence of the Coupling on the Resistance.—The force required to start a train and the resistance on curves of small radii are influenced by the degree of tension given to the couplings. In goods trains, the couplings being usually loose, the trucks are put in motion one after another, and consequently the whole train is started with a smaller expenditure of force than in the case in which the engine has to overcome the inertia of the whole train at once. In passenger trains the couplings are made very tight to prevent oscillation when in rapid motion, and our experiments in these cases have shown that a considerably greater force was required at starting than in the preceding case. Figs. 2600, 2601, give two dynamometrical curves from which the difference of force required to start a train, caused by the mode of coupling, may be clearly seen;—

1. For the goods train .. .. 75, February 13, 1865;
2. For the passenger train .. .. .. (2) 16, June 5, 1866.

Influence of the Speed; Resistance of the Air.—The greater the speed, the greater is the resistance of the air. The oscillation of the carriages, also, increases with the speed, especially upon curves, and the friction of the tire becomes in a proportionate degree greater. Consequently, the resistance of trains generally must depend in a great measure upon the speed.

1. *Passenger Trains.*—Our experiments upon short passenger trains give

For $V = 39^k$ .. .. .. $f = 6^k \cdot 54$, or about 40^k a carriage.
" $V = 46^k$ .. .. .. $f = 7^k \cdot 21$, " 44^k "
" $V = 58^k$ .. .. .. $f = 9^k \cdot 57$, " 58^k "
" $V = 76^k$ .. .. .. $f = 14^k \cdot 55$, " 96^k "

Fig. 2601 gives the curve representing the law of the resistance according to the velocity. The same figure gives the curve of the resistance for trains composed of more than 10 carriages. It will be seen that the law of increase of the ordinates in function of the abscissæ, which represent the velocities, is less rapid. We will give four points of this curve;—

For $V = 35^k$ .. .. .. $f = 5^k \cdot 67$, or about 35^k a carriage.
" $V = 45^k$ .. .. .. $f = 5^k \cdot 98$, " 37^k "
" $V = 52^k$ .. .. .. $f = 6^k \cdot 53$, " 40^k "
" $V = 60^k$ .. .. .. $f = 8^k \cdot 05$, " 48^k "

2. *Goods Trains.*—The nature and length of goods trains being very variable, it is much more difficult to ascertain the influence of the speed. By referring to Table XVIII. it will be seen that the resistance increases by about 1 or 2 per 100 for an increase of speed of 1 kilomètre within the limits of 20 to 30 kilomètres an hour. (See Note G.)

3. *Mixed Trains.*—We find

For $V = 40^k$ .. .. .. $f = 4^k \cdot 67$
" $V = 50^k$ .. .. .. $f = 5^k \cdot 60$

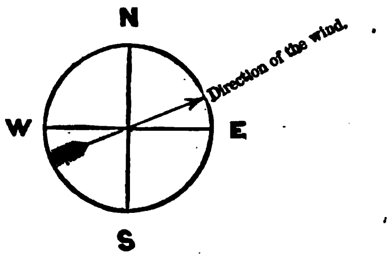
These coefficients are considerably smaller than those for passenger trains. This is because the paying load is much greater in mixed trains, and because the resistance of the air has much less influence on the coefficient of resistance a ton gross weight.

Influence of the External or Atmospheric Wind.—Besides the resistance of the air, we have that due to the atmospheric wind.

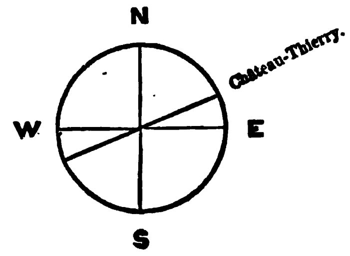
Train No. 9, August 13, 1860 (from Paris to Château-Thierry, Figs. 2611, 2612), and train 20, of the same day (from Château-Thierry to Paris), composed of the same carriages, and moving in the same atmospheric circumstances between 10 o'clock in the morning and 5 o'clock in the afternoon, were both experimented on by means of the dynamometer car.

The direction from Paris to Château-Thierry is shown below, opposite the direction of the wind observed during the journey. The line winds a little, but if we consider the whole of the journey, it will be seen that the train had, on going, the wind nearly behind, and, on returning, the wind was of course a head-wind

2611.



2612.



The absolute velocity of the wind was determined by two observations made, by the compass and vane, within a few minutes of each other. The first was made in the station at Château-Thierry, a little before the departure of train 20; the second during the journey on a long piece of straight line within a kilomètre of Château-Thierry. It may be assumed that, during the interval, the direction and the absolute velocity had not changed.

Thus we knew;—

1. The angle made by the actual direction of the wind with the direction of the train when stationary, equal to 40°.

2. The angle made by the relative direction of the wind with the direction of the train when in motion, equal to 15°.

3. The speed of the train, that is, of the artificial wind created by the motion of the train.

Under these conditions, on account of the swiftness of transport, the vane serves as an anemometer. We may thus construct the parallelogram of the velocities, and deduce the value of the actual velocity of the wind.

The absolute velocity of the wind was, by this means, found to be $8^{m}\cdot40$ a second.

TABLE XVIII.—INFLUENCE OF CURVES UPON TRACTION.

Designation of the Train.	Designation of the Sections of Line.	Speed an hour.	Number of Carriages, &c.	Coefficient of Traction.	Observations.
	kilomètre-post.	kilomètres.		kilogrammes.	
64. March 19, 1863..	140 to 129	27	29	4·28	The distance travelled on a curve is less than 20 per 100 of the total distance.
85. Feb. 27, 1863..	148 „ 166	25	37	4·88	
85. Feb. 27, 1863..	191 „ 198	28	41	5·33	
62. Feb. 27, 1863..	169½ „ 165	26	30	3·65	
62. Feb. 27, 1863..	153 „ 149	28	30	2·63	
85. Feb. 22, 1863..	150 „ 161½	26	37	4·78	
85. Feb. 22, 1863..	189 „ 198½	25	37	4·88	
78. March 17, 1864..	203½ „ 199	29	47	4·82	
78. March 17, 1864..	199 „ 190½	29	47	4·68	
80. March 19, 1864..	139 „ 135	25	30	4·27	
89. March 18, 1864..	148 „ 154	29	38	4·78	
89. March 18, 1864..	154 „ 161	27	38	4·85	
88. March 18, 1864..	204 „ 199	26	26	4·84	
83. April 6, 1864..	57 „ 62	26	44	4·93	
81. April 11, 1864..	120 „ 134	26	43	5·68	
78. April 13, 1864..	197 „ 193	23	55	4·15	
88. April 14, 1864..	203 „ 199	26	35	4·27	
88. April 14, 1864..	199 „ 191	26	35	4·43	
88. April 14, 1864..	169 „ 157	26	38	4·63	
40·69. April 29, 1864..	28½ „ 31	25	31	4·21	
75. Aug. 31, 1864..	9½ „ 14	22	42	3·73	
75. Aug. 31, 1864..	23½ „ 26½	27	42	3·83	
66. Aug. 31, 1864..	41½ „ 39	28	31	3·67	
66. Aug. 31, 1864..	25½ „ 23½	29	38	4·12	
	Means ..	26	37	4·43	

TABLE XVIII.—INFLUENCE OF CURVES UPON TRACTION—*continued.*

Designation of the Train.	Designation of the Sections of Line.	Speed an hour.	Number of Carriages, &c.	Coefficient of Traction.	Observations.
	kilomètre-post.	kilomètres.		kilogrammes.	
85. Nov. 26, 1862..	70 to 78	30	33	6·04	The distance travelled on a curve is between 20 and 50 per 100 of the total distance.
85. Nov. 26, 1862..	86 „ 91	28	33	5·73	
77. Dec. 6, 1862..	67 „ 78	26	28	5·84	
77. Dec. 6, 1862..	89 „ 94	29	28	5·46	
64. March 19, 1863..	124 „ 118	28	29	3·98	
64. March 19, 1863..	113 „ 109	27	29	4·18	
85. Feb. 17, 1863..	176 „ 180	25	39	5·56	
85. Feb. 17, 1863..	180 „ 187	27	39	5·41	
62. Feb. 27, 1863..	185 „ 177	25	28	3·14	
62. Feb. 27, 1863..	164 „ 159	29	30	3·35	
85. Feb. 27, 1863..	163 „ 170	25	37	4·87	
85. Feb. 27, 1863..	176 „ 184½	24	37	5·23	
83. March 16, 1864..	66½ „ 72	22	29	5·95	
83. March 16, 1864..	72 „ 78	24	29	5·00	
80. March 19, 1864..	122 „ 117	29	30	4·23	
80. March 19, 1864..	115 „ 110	27	30	4·55	
81. April 11, 1864..	86 „ 91	28	43	5·37	
81. April 11, 1864..	110 „ 115½	26	43	5·21	
66. April 7, 1864..	73 „ 67	25	34	4·46	
66. April 7, 1864..	61 „ 65	25	34	4·65	
88. April 14, 1864..	182 „ 176	25	35	4·48	
75. Aug. 31, 1864..	57 „ 61	21	41	4·54	
66. Aug. 31, 1864..	62 „ 56½	25	34	4·03	
81. Sept. 1, 1864..	57 „ 60	28	43	4·03	
	Means ..	25	34	4·76	
85. Nov. 26, 1862..	67 to 70	26	33	6·12	The distance travelled on a curve is more than 50 per 100 of the total distance.
85. Nov. 26, 1862..	80 „ 83	30	33	6·02	
85. Nov. 26, 1862..	103 „ 113	28	33	5·60	
77. Dec. 6, 1862..	103 „ 109	24	28	5·80	
64. March 19, 1863..	104 „ 95	30	29	5·59	
63. March 16, 1864..	79 „ 83	26	29	5·20	
89. March 18, 1864..	176½ „ 182½	20	38	5·72	
83. April 6, 1864..	69 „ 76	25	41	5·30	
81. April 11, 1864..	67 „ 71	21	43	5·63	
81. April 11, 1864..	95 „ 103	20	43	5·83	
78. April 12, 1864..	109 „ 104	29	30	3·23	
78. April 13, 1864..	181 „ 177	24	56	4·00	
85. Nov. 26, 1862..	99 „ 102	27	33	5·75	
77. Dec. 6, 1862..	100 „ 103	23	38	5·64	
80. March 19, 1864..	81 „ 78	24	27	4·54	
83. March 16, 1864..	78 „ 82	26	29	5·18	
83. April 6, 1864..	79 „ 82	25	41	5·22	
81. April 11, 1864..	79 „ 82	25	43	5·68	
66. April 7, 1864..	81 „ 78	22	34	4·95	
78. April 12, 1864..	102 „ 99	27	30	3·58	
	Means ..	24	35	5·12	

The resistance observed on the outward and homeward journey, on the same portion of the line and at about the same rate of speed, was, for the same number (thirteen) of carriages,

Between posts 93 and 97	720	and 822	kilogrammes.
„ 76 „ 82	700	„ 857	„
„ 69 „ 66	600	„ 806	„
„ 59 „ 64	552	„ 835	„
„ 26 „ 20	643	„ 817	„
Mean ..	643	„ 827	„

We thus find a difference of 184 kilogrammes (about 30 per 100 of the resistance of the train on the outward journey) due to the influence of the wind having a velocity of $8^{m}\cdot 40$ a second.

These results show that the influence of the wind is considerable, and that the resistance of passenger trains must be very variable, if the weather be not absolutely calm. This fact is corroborated by Tables G to J.

We find as the maximum effect of the wind;—

Passenger Trains.

Experiment No. 83. Speed 46 kilomètres .. .. .. $f = 12^k \cdot 63$
" No. 24. Speed 45 " .. .. .. $f = 10^k \cdot 06$

Goods Trains.

Experiment No. 54. Speed 25 kilomètres .. .. .. $f = 7^k \cdot 68$
" No. 92. Speed 21 " .. .. .. $f = 8^k \cdot 60$

These four experiments were made in a high wind, though not sufficiently violent to be called a storm. It follows from this that, in the absence of extraordinary atmospheric circumstances, the resistance of trains may vary from the single to the double.

Practical Results and Calculations for Determining the Different Terms entering into the Formula of the Power of an Engine.—Formulæ for the Resistance of Trains.—The numerous experiments made by us lead to formulæ giving the resistance r a ton. W. Harding's formula for the resistance r of trains on a level and in a straight line is;—

$$r = 2 \cdot 72 + 0 \cdot 094\,V + \frac{0 \cdot 00484 \times S\,V^2}{P}; \qquad [8]$$

r being the resistance of the train a ton in kilogrammes;
V the speed an hour in kilomètres;
S the section of the front of the train (S = 5 square mètres); and
P the weight of the train in tons.

The results given by this formula are much too great. Its application will be found in Table XIX., where the difference in the values obtained for r will be seen to be considerable. We have preferred to modify the coefficients in this formula without changing its form, which seems to us a very convenient one.

The results of our experiments have led us to the following conclusions;—

1st. That we cannot have a simple formula applicable to any train;

2nd. That the trains must be arranged in two groups, the first comprising goods trains moving at from 12 to 32 kilomètres an hour; the second, all trains moving at a rate of speed greater than 32 kilomètres.

TABLE XIX.—APPLICATION OF HARDING'S FORMULA, $R = 2 \cdot 72 + 0 \cdot 094\,V + \frac{0 \cdot 00484 \times S \times V^2}{P}$.

Goods and Mixed Trains.

Designation of the Train.	Speed an hour.	Gross Weight in tons.	Value of the Second Term.	Value of the Third Term.	Total Value calculated for R.	Value found by Experiment.	Excess of the Value found by Calculation.	Observations.
	kiloms.				kils.			
199. June 20, 1862	20	567	1·88	0·02	4·62	3·12	1·50	S is the section of the front of the train. S = 5 sq. mètres.
62. Feb. 27, 1863	25	306	2·35	0·05	5·12	3·14	1·98	
40·62. April 28, 1864	26	509	2·45	0·03	5·20	3·20	2·00	
66. Aug. 31, 1864	17	332	1·60	0·02	5·34	3·14	1·20	
567. June 27, 1862	29	221	2·73	0·09	5·54	4·43	1·11	
562. June 15, 1862	29	301	2·73	0·07	5·52	4·32	1·20	
64. March 19, 1863	28	321	2·63	0·06	5·41	4·01	1·40	
62. Feb. 27, 1863	31	396	2·92	0·07	5·71	3·18	2·53	
78. March 17, 1863	31	474	2·92	0·04	5·68	3·98	1·70	
88. March 18, 1864	29	249	2·73	0·08	5·53	4·05	1·48	
78. April 12, 1864	32	300	3·02	0·08	5·80	4·33	1·47	
78. April 12, 1864	29	326	2·73	0·06	5·51	3·54	1·97	
78. April 13, 1864	31	536	2·92	0·04	5·70	4·41	1·29	
78. April 13, 1864	31	536	2·92	0·04	5·68	3·54	2·14	
66. Aug. 31, 1864	30	296	2·83	0·07	5·62	3·71	1·91	
100. April 25, 1862	36	239	3·38	0·13	6·23	4·64	1·59	
100. April 25, 1862	38	227	3·58	0·15	6·45	4·60	1·85	
38. Dec. 5, 1862	37	200	3·48	0·16	6·36	4·67	1·69	
38. Dec. 16, 1862	39	174	3·67	0·21	6·60	4·43	2·17	
46. Nov. 19, 1864	44	120	4·14	0·39	7·25	5·18	2·07	
100. April 16, 1862	34	207	3 20	0·13	6·05	5·22	0·83	
100. April 16, 1862	42	190	3·95	0·10	6·77	5·75	1·02	

1st Group.—Goods Trains moving at from 12 to 32 kilomètres an hour upon a level, the curves being of a long radius, and the weather fine.—When the rate of speed is low, the term in V^2 of the equation [8] has so little importance that it may be suppressed. The nature of the lubricating substance has a notable influence, occasioning a considerable change in the coefficients. The two

following formulæ are the result of the tentative processes to which we were obliged to have recourse:—

For trains lubricated with oil,

$$r = 1\cdot65 + 0\cdot05\,V. \qquad [a]$$

For trains lubricated with grease,

$$r = 2\cdot30 + 0\cdot05\,V. \qquad [b]$$

These formulæ show the advantage possessed by oil over grease at a temperature of 15°. Below this temperature, the advantage increases rapidly; above, on the contrary, it becomes less. Table XX. gives the results of these formulæ applied to our experiments; it will be seen that they differ but little from those obtained by actual trial.

TABLE XX.—APPLICATION OF A NEW FORMULA TO THE CALCULATION OF THE RESISTANCE OF GOODS TRAINS, $R = 2\cdot30 + 0\cdot05\,V$.

Designation of the Train.	Speed an hour.	Value of the Term in V.	Value of R by Calculation.	Value of R by Experiment.	Excess of the Value by Calculation
	kilomètres.		kilogrammes.	kilogrammes.	
199. June 20, 1862	20	1·00	3·30	3·12	0·18
62. Feb. 27, 1863	25	1·25	3·55	3·14	0·41
40·62. April 28, 1864	26	1·30	3·60	3·20	0·40
66. Aug. 31, 1864	17	0·85	3·15	3·14	0·01
567. June 27, 1862	29	1·45	3·75	4·43	0·68
562. June 15, 1862	29	1·45	3·75	4·32	0·57
64. March 19, 1863	28	1·40	3·70	4·01	0·31
62. Feb. 27, 1863	31	1·55	3·85	3·18	0·67
78. March 17, 1864	31	1·55	3·85	3·98	0·13
88. March 18, 1864	29	1·45	3·75	4·05	0·30
78. April 12, 1864	32	1·60	3·90	4·33	0·43
78. April 12, 1864	29	1·45	3·75	3·54	0·21
78. April 13, 1864	31	1·55	3·85	4·41	0·51
78. April 13, 1864	31	1·55	3·85	3·54	0·31
66. Aug. 31, 1864	30	1·50	3·80	3·71	0·09

TABLE XXI.—APPLICATION OF HARDING'S FORMULA, $R = 2\cdot72 + 0\cdot094\,V + \dfrac{0\cdot00484 \times S \times V^2}{P}$.

Passenger Trains.

Designation of the Train.	Speed an hour.	Gross Weight in tons.	Value of the Second Term.	Value of the Third Term.	Total Value by Calculation.	Value by Experiment.	Excess of the Value by Calculation.
	kilomètres.				kilogs.	kilogs.	
35. April 27, 1862	47	90	4·40	0·58	7·70	6·24	1·46
36. May 6, 1862	46	101	4·32	0·52	7·56	5·54	2·12
40·26. April 28, 1866	44	101	4·13	0·48	7·33	6·43	0·90
44. June 8, 1866	45	107	4·23	0·47	7·42	5·73	1·69
40·35. April 24, 1866	45	50	4·23	1·00	7·95	7·44	0·51
40·35. April 26, 1866	41	56	3·86	0·75	7·33	7·27	0·06
2·16. June 6, 1866	46	58	4·32	0·91	7·95	7·56	0·39
35. April 27, 1862	54	90	5·10	0·81	8·63	6·95	1·68
35. May 1, 1862	50	101	4·72	0·62	8·06	6·03	2·03
36. May 6, 1862	54	101	5·10	0·72	8·54	6·03	2·51
35. May 7, 1862	50	106	4·72	0·59	8·03	6·71	1·32
40·23. April 28, 1866	52	101	4·90	0·67	8·29	6·54	1·75
35. June 4, 1866	54	105	5·10	0·69	8·51	6·95	1·56
36. April 30, 1862	58	91	5·45	0·92	9·09	8·03	1 06
35. Nov. 19, 1864	59	98	5·56	0·88	9·16	7·95	1 21
35. June 4, 1866	63	105	5·93	0·96	9·63	8·16	1 47
40·35. April 24, 1866	65	50	6·12	2·12	10·96	9·80	1·16
40·32. April 25, 1866	60	55	5·65	1·65	10·02	9·10	0·92
2·16. June 5, 1866	61	61	5·75	1·55	10·02	9·80	0·22
33. March 14, 1866	76	53	7·17	2·73	12·62	14·55	−1·93

2nd Group.—All Trains moving at a rate of speed greater than 32 kilomètres, upon a level, the curves being of a long radius.—Table XXI. gives the results of the application of Harding's formula to these trains. They are much too great for heavy trains, are nearly true for light stopping trains, and are too small for express trains of eight carriages. After many trials, we have been obliged to admit three series of coefficients. (See Table XXII.)

Trains moving at from 32 to 50 kilomètres an hour,

$$r = 1 \cdot 80 + 0 \cdot 80\,V + \frac{0 \cdot 009 \times S \times V^2}{P}. \qquad [c]$$

Trains moving at from 50 to 65 kilomètres an hour,

$$r = 1 \cdot 80 + 0 \cdot 08\,V + \frac{0 \cdot 006 \times S \times V^2}{P} \qquad [d]$$

Trains moving at 70 kilomètres an hour, and above,

$$r = 1 \cdot 80 + 0 \cdot 14\,V + \frac{0 \cdot 004 \times S \times V^2}{P}. \qquad [e]$$

To show the necessity of these different coefficients, we must remark that, in these formulæ, the term in V represents the resistance at the circumference of the wheels, which resistance increases with the speed and the oscillation, and that the term in V^2 represents the resistance of the air; the heavier the train, the more is the resistance due to the surface exposed to the wind proportionately reduced. The reason why this term contains the weight P as a denominator is therefore evident.

The formulæ [c], [d], and [e], give results that agree perfectly with those obtained by experiment. r being the coefficient of resistance a ton on a level and in a straight line, the additional resistance due to gradients, curves, and so on, may be calculated by the methods we have already given.

TABLE XXII.—APPLICATION OF NEW FORMULÆ TO THE RESISTANCE OF PASSENGER TRAINS.

Designation of the Train.	Speed an hour.	Gross Weight in tons.	Value of the Second Term.	Value of the Third Term.	Total Value by Calculation.	Total Value by Experiment.	Excess of the Value by Calculation.	Observations.
	kiloms.				kilogs.	kilogs.		
100. April 25, 1862	36	239	2·88	0·23	4·91	4·64	0·27	Speed from 32 to 50 kiloms. an hour.
100. April 25, 1862	38	227	3·04	0·26	5·10	4·60	0·50	$R = 1 \cdot 80 + 0 \cdot 08\,V + \frac{0 \cdot 009 \times S\,V^2}{P}$.
88. Dec. 5, 1862	37	200	2·96	0·29	5·05	4·67	0·38	
88. Dec. 16, 1862	39	174	3·12	0·38	5·30	4·43	0·87	
46. Nov. 19, 1864	44	120	3·52	0·70	6·02	5·18	0·84	
100. April 16, 1862	34	207	2·72	0·23	4·75	5·22	−0·47	
100. April 16, 1862	42	190	3·36	0·19	5·35	5·75	−0·40	
35. April 27, 1862	47	90	3·76	1·11	6·67	6·24	0·43	
36. May 6, 1862	46	101	3·68	0·95	6·43	5·54	0·89	
40·26. April 28, 1866	44	101	3·52	0·87	6·19	6·43	−0·24	
44. June 8, 1866	45	107	3·60	0·85	6·25	5·73	0·52	
40·35. April 24, 1866	45	50	3·60	1·83	7·23	7·95	−0·72	
40·35. April 26, 1866	41	56	3·28	1·37	6·45	7·33	−0·88	
2·16. June 6, 1866	46	58	3·68	1·62	7·10	7·95	−0·85	
35. April 27, 1862	54	90	4·32	0·97	7·09	6·95	0·14	Speed from 50 to 65 kiloms. an hour.
35. May 1, 1862	50	101	4·00	0·74	6·54	6·03	0·51	$R = 1 \cdot 80 + 0 \cdot 08\,V + \frac{0 \cdot 006 \times S\,V^2}{P}$.
36. May 6, 1862	54	101	4·32	0·86	6·98	6·03	0·65	
35. May 7, 1862	50	106	4·00	0·71	6·51	6·71	−0·20	
40 23 April 28, 1866	52	101	4·16	0·80	6·76	6·54	0·22	
35. June 4, 1866	54	105	4·32	0·82	6·94	6·95	−0·01	
36. April 30, 1862	58	91	4·64	1·10	7·54	8·03	−0·49	
35. Nov. 19, 1864	59	98	4·72	1·05	7·57	7·95	−0·38	
35. June 4, 1866	63	105	5·04	1·15	7·99	8·16	−0·17	
40 35. April 24, 1866	65	50	5·20	2·55	9·55	9·80	−0·25	
40·32. April 25, 1866	60	55	4·80	1·97	8·57	9·10	−0·53	
2·16. June 5, 1866	61	61	4·88	1·86	8·54	9·80	−1·26	
33. March 14, 1866	76	53	10 64	2·18	14·62	14·55	0·07	Speed > 70 kiloms. $R = 1 \cdot 80 + 0 \cdot 14\,V + \frac{0 \cdot 004 \times S\,V^2}{P}$.

Actual Horse-power to the Unit of Heating Surface.—Table XXIII. gives the maximum amount of work developed by different kinds of engines during the course of our experiments. The highest rates of speed may practically be fixed as follows;—

Crampton's engine	V = 80 kilomètres,	$22^m \cdot 30$	a second.
Mixed engines	V = 55 ”	$15^m \cdot 30$	”
Goods engine (wheels of $1^m \cdot 40$)	V = 30 ”	$8^m \cdot 30$	”
” (wheels of $1^m \cdot 30$)	V = 26 ”	$7^m \cdot 20$	”
” (8 wheels coupled)	V = 24 ”	$6^m \cdot 70$	”

Whence we conclude that at their greatest rates of speed, our several engines are capable of developing the following amounts of work:—

Crampton's engine	400 horse-power.
Mixed engines	300 „
Goods engine (wheels of $1^{m}\cdot40$)	300 „
„ „ (wheels of $1^{m}\cdot30$)	275 „
„ „ (8 wheels coupled)	400 „

Dividing the work by the heating surfaces of the engines, we obtain the actual horse-power to the square mètre. We have

Crampton's engine	4·3 horse-power.
Mixed engine (type 14)	3·0 „
„ „ (type 12)	3·6 „
Goods engine (type 20)	2·4 „
„ „ (type 15)	2·7 „
„ „ (8 wheels coupled)	2·0 „

follows from the above figures that the work in horse-power to the unit of heating surface increases with the speed, and with the dimensions of the furnace relatively to the total heating surface. Now, the speed which a locomotive is capable of maintaining, while exerting a given force, depends on the production of steam. The results of our experiments under this head will be found in Note C, and Table XXVIII.

TABLE XXIII.—GREATEST VALUE OF THE WORK OF ENGINES ACCORDING TO EXPERIMENT.

Designation of the Train.	Kind of Engine.	Speed an hour.	Work upon the Coupling.	Work to move the Motor.	Total Work at the circumference of the Driving-wheels.	Mean of the Work for each kind.	Observations.
		kiloms.	h.-p.	h.-p.	h.-p.	h.-p.	
33. March 13, 1866	Crampton's ..	78	262	115 (1)	377	392	
33. March 15, 1866	„ ..	74	297	110	407		
1·16. June 7, 1866	Free wheels.—Type 1 ..	42	132	87 (2)	219	204	
1·35. June 4, 1866	„ „	37	113	80	193		
1·38. July 21, 1866	„ „	44	110	91	201		
36. Dec. 10, 1862	Mixed.—Type 14	45	204	58	261	297	
40·35. April 26, 1866	„ „ 12	70	159	120	279		
40·34. April 27, 1866	„ „ 12	48	175	116	291		
40·23. April 28, 1866	„ „ 14	47	244	101	345 (3)		
35. June 4, 1866	„ „ 14	63	227	81	308		
2·65. July 21, 1865	Goods.—Type 20	18	242	53	295	295	
1·68. July 8, 1864	„ „ 20	25	230	41	271		
1·67. July 6, 1864	„ „ 20	26	250	77	327		
3·64. June 22, 1864	„ „ 20	24	244	49	293		
1·68. June 21, 1864	„ „ 20	20	249	44	293		
1·68. June 20, 1864	„ „ 20	20	250	44	294		
89. April 14, 1864	Goods.—Type 15	24	239	33	272	261	
91. April 13, 1864	„ „ 15	28	225	38	263		
89. March 18, 1864	„ „ 15	31	232	43	275		
140. March 21, 1864	„ „ 15	18	183	50	233		
12·72. Jan. 13, 1866	Eight wheels coupled ..	21	297	71	368	346	
12·80. Jan. 11, 1866	„ „	16	278	62	340		
12·78. Jan. 12, 1866	„ „	23	265	71	336		
12·86. Dec. 22, 1865	„ „	25	262	78	340		
E 74. March 21, 1867	„ „	15	200	127	327		
E 74. March 22, 1867	„ „	17	263	104	367		

(1) The work required to move the motor has been computed at 8 kilogrammes a ton, according to experiments made upon engines with free wheels and upon tenders.

(2) The three experiments upon engines of type 1 were made with the escape closed. The production was difficult.

(3) This large amount of work of 345 horse-power was maintained during a short distance only.

Adhesion of Locomotives.—Table XXIV. contains trains in which a slipping of the wheels was observed. It gives the value of the adhesion of the engine when the lower limit was reached.

As an example, let us take train 140, March 21, 1863; goods engine, type 15; adhesive weight = 30,000 kilogrammes; nature of the line = gradient of 9 millimètres; temperature = 7°; wet and windy.—The tractive force upon the couplings of the tender was in this case 2850 kilogrammes: to find the total tangential force, we must add 700 kilogrammes expended in moving the motor itself (see Table XXIV.), which gives 3550 kilogrammes. The coefficient of adhesion was, therefore, $\frac{3550}{30000} = \frac{1}{8\cdot4}$.

In this case, notwithstanding the slipping, the speed was not less than 15 kilomètres an hour. To realize these conditions, the engines must be provided with sand-boxes in good working order.

It will be seen from Table XXIV. that during our experiments the coefficient of adhesion has been as low as $\frac{1}{13}$, but this was an exceptional case. We could not base our regulations for loading upon this coefficient.

TABLE XXIV.—DYNAMOMETRICAL EXPERIMENTS.—MINIMUM ADHESION.—CASES OF SLIPPING.

Numbers.	Designation of the Train.	Gross Weight of the Train.	Kind of Engine.	Adhesive Weight.	Nature of the Line.	Atmospheric Circumstances.	Tractive Force.	Force to move the Motor.	Total Tangential Force.	Coefficient of Adhesion.
		tons.		kilogs.	millimètres.		kilogs.	kilogs.	kilogs.	
1	140. March 21, 1863 ..	211	Goods.—Type 15	30,000	Incline 9 ..	Wet. T = + 7° ..	2850	700	3550	$\frac{1}{8\cdot4}$
2	91. April 13, 1864 ..	323	" " 15	30,000	Level	T = + 10° ..	2800	450	3250	$\frac{1}{9\cdot2}$
3	81. April 14, 1864 ..	267	" " 15	30,000	Incline 0·40 ..	T = + 10° ..	3120	260	3380	$\frac{1}{8\cdot8}$
4	1·68. July 8, 1864 ..	301	" " 20	33,000	" 8 ..	Damp weather ..	2110	460	2570	$\frac{1}{12\cdot8}$
5	1·71. Feb. 4, 1867 ..	334	" " 15 and 20 ..	63,000	" 9·25 ..	Light rain	4200	1480	5680	$\frac{1}{11\cdot1}$
6	2·16. July 21, 1865 ..	97	Mixed.—Type 14	20,000	" 5 ..	Wet. T = + 20° ..	1290	550	1840	$\frac{1}{11}$
7	33. March 15, 1866 ..	52	Crampton's	10,000	Level	Nanteuil tunnel ..	1100	500	1600	$\frac{1}{6\cdot2}$
8	1·16. June 7, 1866 ..	53	Free wheels.—Type 1 ..	9,800	Incline 5 ..	Billy tunnel	830	380	1210	$\frac{1}{8}$
9	1·38. July 21, 1865 ..	40	" " 1 ..	9,800	" 5 ..	"	680	380	1060	$\frac{1}{9\cdot2}$

TABLE XXV.—DYNAMOMETRICAL EXPERIMENTS.—MAXIMUM ADHESION.

Designation of the Train.	Gross Weight of the Train.	Kind of Engine.	Adhesive Weight.	Nature of the Line.	Atmospheric Circumstances.	Tractive Force.	Force to move the Motor.	Total Tangential Force.	Coefficient of Adhesion.	Observations.
	tons.		kilogs.	millimètres.		kilogs.	kilogs.	kilogs.		
1·68. June 20, 1864	325	Type 20	33,000	Incline 6 ..	Dry weather	3800	590	4390	$\frac{1}{7\cdot5}$	Drawn by a mixed engine.
1·68. July 8, 1864	334	" 20	33,000	" 6 ..	Damp	3750	590	4340	$\frac{1}{7\cdot6}$	
1·68. July 27, 1864	393	" 14	20,000	" 6 ..	Dry	3550	500	4050	$\frac{1}{5}$	
1·43. July 19, 1865	64	" 1	9,800	" 9·25	"	950	530	1840	$\frac{1}{6}$	
31. Dec. 21, 1865	73	" 7	19,000	" 8 ..	"	1510	620	2130	$\frac{1}{8}$	
33. March 13, 1866	52	Crampton	10,000	Level	Nanteuil tunnel	920	500	1420	$\frac{1}{7}$	
33. March 15, 1866	53	"	10,000	Incline 5 ..	Dry	1180	500	1680	$\frac{1}{6}$	
40·32. April 25, 1866	55	Type 2 bis	11,000	" 6 ..	"	850	530	1380	$\frac{1}{8}$	
1·35. June 4, 1866	45	" 1	9,800	" 9·25	A little damp	830	530	1360	$\frac{1}{7\cdot2}$	
1·16. June 7, 1866	53	" 1	9,800	" 9 ..	Dry	900	530	1430	$\frac{1}{6\cdot8}$	
2·65. July 20, 1865	255	" 20	33,000	" 10 ..	"	3710	740	4450	$\frac{1}{7\cdot4}$	
2·65. July 21, 1865	259	" 20	33,000	" 10 ..	"	3930	740	4670	$\frac{1}{7}$	
12·72. Jan. 13, 1866	522	Eight coupled wheels	46,000	" 5 ..	"	4680	990	5670	$\frac{1}{8\cdot1}$	
12·80. Jan. 11, 1866	571	" " "	46,000	" 5 ..	Wet, $t = + 7°$	4780	990	5770	$\frac{1}{8}$	
12·72. Jan. 12, 1866	522	" " "	46,000	" 5 ..	Dry	4730	990	5720	$\frac{1}{8}$	

12·72. Jan. 11,	1866	523	Eight coupled wheels	46,000	Incline 5 ..	Heavy rain, $t = +3°$ ..	6210	990	7200	$\frac{1}{6·3}$	Force in a difficult passage.
1·69. Jan. 14,	1867	268	Types 20 and 14 ..	53,000	„ 9·25	Dry	4250	1340	5590	$\frac{1}{9·5}$	Double traction.
1·38. July 21,	1865	40	Type 1	9,800	„ 9 ..	„	700	530	1230	$\frac{1}{8}$	
E 63. March 20,	1867	156	„ 20	33,000	„ 15 ..	Rain and fog	2746	1040	3786	$\frac{1}{8·7}$	
E 63. March 20,	1867	156	„ 20	33,000	„ 16·90	„ „	3035	1200	4235	$\frac{1}{7·8}$	
E 63. March 20,	1867	156	„ 20	33,000	„ 19·80	„ „	3460	1300	4760	$\frac{1}{6·9}$	
E 74. March 22,	1867	233	Eight coupled wheels	46,000	„ 15·50	Windy. A little snow ..	4250	1700	5950	$\frac{1}{7·7}$	
91. April 13,	1864	338	Type 15	30,000	„ 0·40	Dry	4750	274	5020	$\frac{1}{5·9}$	Start from station.
89. April 14,	1864	227	„ 15	30,000	„ 3·20	„	4350	400	4750	$\frac{1}{6·3}$	
66. April 15,	1864	377	„ 20	33,000	„ 3·50	„	5700	440	6140	$\frac{1}{5·3}$	
40·69. April 28,	1864	285	„ 11	27,000	Level	„	5800	230	6030	$\frac{1}{4·4}$	
40·69. April 29,	1864	184	„ 12	22,000	Incline 3·50	„	3520	370	3890	$\frac{1}{5·6}$	
1·67. July 6,	1864	163	„ 20	33,000	„ 10 ..	„	5420	790	6210	$\frac{1}{5·3}$	Start after a signal to stop.
1·67. July 26,	1864	170	„ 15	30,000	Level	Heavy rain	4480	250	4730	$\frac{1}{6·3}$	
75. Aug. 31,	1864	264	„ 11	27,000	Incline 5 ..	Dry	4890	450	5340	$\frac{1}{5}$	
12·80. Jan. 12,	1866	571	Eight coupled wheels	46,000	„ 5 ..	Rainy	8200	980	9180	$\frac{1}{5}$	Rupture of coupling.
12·80. Jan. 12,	1866	571	„ „ „	46,000	„ 3 ..	„	8500	850	9350	$\frac{1}{4·9}$	Start from station.
12·80. Dec. 22,	1865	476	„ „ „	46,000	„ 8 ..	Dry	7850	850	8700	$\frac{1}{5·2}$	
12·74. Jan. 9,	1867	370	Type 20	33,000	Level	„	7150	260	7410	$\frac{1}{4·4}$	
E 63. March 22,	1867	135	„ 20	33,000	Incline 20 ..	Snow and rain, $t = +3°$	5000	1300	6300	$\frac{1}{5·2}$	Start after signal to stop.
E 63. March 20,	1867	156	„ 20	33,000	„ 20 ..	Rain and fog, $t = 14°$ ..	7200	1300	8500	$\frac{1}{3·9}$	
35. Nov. 17,	1864	82	„ 14	20,000	„ 5 ..	Damp, $t = 8°$ ..	2830	450	3280	$\frac{1}{6·1}$	
46. Nov. 17,	1864	172	„ 14	20,000	Level	Rain, $t = +11°$	3200	200	3400	$\frac{1}{5·8}$	Start from station.
31. May 4,	1865	70	„ 7	19,000	„	Dry	2880	200	3080	$\frac{1}{6·1}$	
1·38. July 21,	1869	40	„ 1	9,800	„	„	1160	160	1320	$\frac{1}{7·4}$	
1·43. July 19,	1865	64	„ 1	9,800	„	„	1430	160	1590	$\frac{1}{6·2}$	
31. Dec. 21,	1865	73	„ 7	19,000	„	„	2230	200	2430	$\frac{1}{7·7}$	
33. March 15,	1866	53	Crampton	10,000	„	„	1430	200	1630	$\frac{1}{6·1}$	
33. March 16,	1866	53	„	10,000	„	„	1560	200	1760	$\frac{1}{5·7}$	
40·32. April 25,	1866	55	Type 2 bis	11,000	„	„	1600	200	1800	$\frac{1}{6·1}$	
40·32. April 25,	1866	77	„ 12	22,000	„	„	3200	200	3400	$\frac{1}{6·4}$	
40·35. April 26,	1866	87	„ 12	22,000	„	„	3400	200	3600	$\frac{1}{6·1}$	
40·35. April 26,	1866	56	„ 2 bis	11,000	„	„	1540	200	1740	$\frac{1}{6·3}$	
40·26. April 28,	1866	101	„ 14	20,000	„	„	3630	200	3830	$\frac{1}{5·7}$	
1·36. July 4,	1867	30	„ 1	9,800	„	Rain	1350	160	1510	$\frac{1}{6·5}$	

Table XXV. contains trains in the case of which traction was accomplished with very high values of adhesion without slipping. At the top are given the coefficients observed when the train was in motion, and which correspond to a long distance; at the bottom, the coefficients observed at starting, and due to an instantaneous effort.

The maximum value of the coefficient, during motion, was $\frac{1}{5}$. This is the higher limit of adhesion that will serve to regulate the loads which may be drawn by engines in fine weather. The minimum loads to be drawn in all weathers may be determined by taking the coefficients as $\frac{1}{9}$. In winter we cannot reckon upon an adhesion greater than this.

The variation in the speed of trains has considerable influence on adhesion. It has been observed that a train of eight carriages, moving on a level at the rate of 70 kilomètres an hour, requires as much adhesive force as the same train moving at 40 kilomètres up an incline of 9 millimètres.

At starting, the limit of adhesion is, on most occasions, nearly reached, and the coefficients found in these cases are higher than those found when the train is in motion. In practice, we may admit the coefficient at starting as $\frac{1}{5}$.

Practical Formula of the Power of an Engine.—The practical formula which we are about to give is derived solely from the results of our experiments.

Let P be the gross weight in tons which an engine is capable of drawing at a rate of speed V upon a line of known nature;
- r resistance of the weight P a ton;
- P' the weight in tons of the engine and tender;
- r' the resistance of the weight P' a ton, considering the engine and tender as mere vehicles;
- S the heating surface of the engine;
- N the actual horse-power to the unit of heating surface;
- P'' the adhesive weight of the engine, that is, the weight resting upon the points of the driving wheels in contact with the rails;
- m the coefficient of adhesion of the engine.

The force of the circumference of the wheels will be $Pr + P'r'$.

V being the speed in mètres a second, the work to be effected is $(Pr + P'r')V$. And we ought to have

$$(Pr + P'r')V \lesseqgtr S \times N \times 75. \qquad [F]$$

Besides this, to avoid slipping, we must have

$$(Pr + P'r') \lesseqgtr mP''. \qquad [F']$$

By means of these two formulæ the load which a given engine is capable of drawing may be readily calculated. They will equally serve to solve the inverse problem which will oftener occur in practice.

To determine the principal elements of a locomotive to draw a load P at a rate of speed V upon a line of known nature, an approximative value must be given to P' in equation [F], when the value of S may be deduced. Equation [F'] will enable us to determine P''.

The problem will have received its best solution if we succeed in making equal pair by pair the members of the relations [F] and [F']. (For the other parts of the engine, see Note E.)

Note A.—Vis viva of a Pair of Wheels.—In making dynamometrical experiments on the resistance of trains, it may happen that each division of the distance upon which the experiments were made was travelled over at a uniform rate of speed; nothing can be easier than to measure the resistance of the train in such cases. But it happens very often that the speed varies considerably; in this case more calculation is requisite to find the coefficient of resistance. The formula which we have employed is the following:—

Let V_0 be the initial velocity in kilomètres an hour;
- V_1 the final velocity also in kilomètres an hour;
- P the weight of the train in tons;
- p the weight in kilogrammes of a revolving piece, such as wheel or axle;
- K the radius of gyration of a revolving piece;
- R the radius of the circle of revolution;
- n the number of vehicles;
- x the unknown coefficient of resistance a ton, at the mean speed of $\frac{V_1 + V_0}{2}$;
- F the mean tractive force in kilogrammes; and
- s the space traversed in mètres.

We have

$$F \times s = x \times P \times s \pm \frac{1}{2g}\left(P \times 1000 + \Sigma p \frac{K^2}{R^2}\right) \times \frac{V_1^2 - V_0^2}{12 \cdot 96}. \qquad [1]$$

To find the value of the term $\Sigma p \frac{K^2}{R^2}$, we will apply the calculation to the circumference and to the axle. Say for the circumference $p' \times \frac{K'^2}{R^2}$.

We are here considering the rolling stock of the Eastern Railway Company, to whom most of the trains experimented on belonged. The outer diameter of the wheel is $1^m \cdot 03$ when the wheel is new. The tire when new is 55 millimètres in thickness; it is used till this thickness has been worn down to 25 millimètres. Therefore, considering the wheel as half worn out, we shall have

$$2\,R = 1^m \cdot 00. \quad K'^2 = \left(\frac{r + r'}{2}\right)^2 + \frac{1}{4} \times \left(\frac{r' - r}{2}\right)^2.$$

Whence we deduce $K' = 0 \cdot 48$, that is, K' is very nearly equal to the radius of the circle of revolution $\frac{K'^2}{R^2} = \frac{0 \cdot 48^2}{0 \cdot 50^2} = 0 \cdot 920$.

The weight of two pieces of tire, at the mean thickness of 40 millimètres, is 264 kilogrammes. Therefore, for a pair, we shall have $p' \frac{K'^2}{R^2} = 264 \times 0 \cdot 92 = 243$

For the axle let us say $p'' \times \frac{K''^2}{R^2}$

This term is very small. We find $p'' \times \frac{K''^2}{R^2} = 1 \cdot 08$.

For a pair of wheels we have $p' \frac{K'^2}{R^2} + p'' \frac{K''^2}{R^2} = 244 \cdot 08$.

For the carriage with two axles, $\Sigma p \frac{K^2}{R^2} = 488$.

And for the whole train, $\Sigma p \frac{K^2}{R^2} = n \times 488$.

Having made the necessary substitution and reduction, formula [1] becomes

$$F \times s = x \times P \times s \pm 0 \cdot 004\,(P \times 1000 + n \times 488) \times (V_1^2 - V_0^2). \quad [2]$$

This formula was applied in calculating Tables A to J. By means of it we may calculate the mean resistance a ton x, even when the speed has varied throughout the time of the experiment.

Suppose a single carriage impelled at an initial velocity V_0 and then left to itself till it stopped. The third term of formula [2] is then $0 \cdot 004 \times (1000\,P + 488) \times V_0^2$.

Substituting the weight in kilogrammes P′ for the weight in tons P. and the speed in mètres a second V for the speed in kilomètres an hour V_0, we have

$$\begin{aligned} P' &= m \times g, \\ P &= 0 \cdot 001 \times P', \\ V_0 &= 3 \cdot 60 \times V; \end{aligned}$$

and the above term becomes $\left(\frac{1}{2} m + 25\right) \times V^2$.

Thus the rotating *vis viva* of a pair of carriage-wheels is expressed, in kilogrammètres, by $12 \cdot 5\,V^2$.

The same calculation gives the following values of the *vis viva* of some of the wheels to which our experiments apply;—

1. For a pair of tender-wheels of $1^m \cdot 20$, $18 \cdot 4 \times V^2$;
2. For a pair of engine-wheels of $1^m \cdot 30$, $20 \times V^2$;
3. For a pair of engine-wheels of $1^m \cdot 68$, $27 \cdot 4 \times V^2$.

Note B.—Modification of the Dynamometer for the purpose of Calculating the Resistance caused by a Brake.—For the purpose of measuring the resistance caused by a brake, a cross-bar *b c* of wrought iron was fixed to the traction-bar. To the ends of this cross-bar were attached pieces connected with the hinder buffers, as shown in the figure.

If we have a brake in front of the dynamometer car, the front buffers of the car strike against and press upon this obstacle, and its hinder buffers *a* receive the thrust of the train rolling behind, transmitting it by means of the piece *b c* to the traction-bar of the dynamometer. In this way the thrust is made to act upon the dynamometrical spring, and we are thus enabled to measure accurately the influence of the brake.

Note C.—Production of Steam.—The speed of a locomotive while exerting a given force, depends on its production of steam. Tables XXVI., XXVII., and XXVIII., give the maximum consumption of water observed by us and the maximum value of the work in horse-power.

The maximum value of the work in horse-power includes the work developed upon the couplings of the tender, and the work required to move the motor itself. This latter work was computed in accordance with the contents of Table III. Where the total mean of the work is not given, that portion of the line was too irregular to allow us to find a mean. The water was measured in the tender by means of a graduated scale. The consumption of water does not correspond exactly to the production of steam, because a certain quantity of water is carried off; but at present we will not consider this quantity.

TABLE XXVI.—CONSUMPTION OF WATER.—PASSENGER TRAINS.

Designation of the Train. 1		Kind of Engine. 2		Gross Weight of the Train. 3	No. of Carriages. 4	Extreme Stations. 5	Distance run over. 6	Mean Inclination of the Line. 7	Greatest Gradient to be ascended. 8	Mean Speed. 9	Resistance of the Train a ton. 10	Total Consumption of Water. 11	Mean useful Work. 12	Consumption of Water: a kilomètre. 13	a ton and to the kilomètre. 14	a carriage and to the kilomètre. 15	to the useful horse-power and to the kilomètre. 16	
				tons.			kiloms.	mills.	mills.	kiloms.	kilogs.	litres.	h.-p.	litres.	litres.	litres.	litres.	
33. March 13, 1866.	Express ..	Crampton's ..		52	8	Paris, Epernay ..	141	0	5	73	17·29	7830	247	54	1·06	6·87 } 7·04	0·22	
33. March 14, 1866.	" ..	" ..		53	8	" " ..	141	0	5	71 } 72	14·45	7570	201	53 } 56	1·00 } 1·08	6·62	0·26 } 0·23	1
33. March 15, 1866.	" ..	" ..		52	8	" " ..	141	0	5	73	19·75	8680	280	61	1·17	7·62	0·22	
32. March 15, 1866.	Semi-direct	Mixed.—Type	14	78	12	Château, Paris ..	94	0	5	45	11·10	5670	144	60	0·83	5·00	0·41	
35. Nov. 17, 1864.	"	" "	14	82	14	Paris, Epernay ..	141	0	5	48	8·43	9300	147	66	0·80 } 0·72	4·72 } 4·45	0·45	2
32. March 13, 1866.	"	" "	14	88	14	Château, Paris ..	94	0	5	47 } 47	8·04	5280	131	56 } 58	0·63	4·00	0·45 } 0·44	
32. March 14, 1866.	"	" "	12	78	12	" " ..	94	0	5	46	9·02	4616	132	49	0·62	4·08	0·47	
44. June 8, 1866.	"	Mixed.—Type	14	107	17	Epernay, Paris ..	141	0	5	45	5·73	8270	104	57	0·53	3·35	0·56	
35. June 4, 1866.	"	" "	14	105	17	Meaux, Château	51	0	5	49	7·03	3312	180	64	0·61	3·77	0·35	
40·35. April 24, 1866.	Stopping Train	" "	12	67	11	Nangis, Romilly	59	0·8	5	46	12·50	3250	..	56	0·83	5·09		
40·32. April 25, 1866.	"	" "	12	75	12	Romilly, Paris ..	128	0·3	6	40	6·26	7300	..	57	0·76	4·75		
40·35. April 26, 1866.	"	" "	12	81	13	Nangis, Romilly	59	0·8	5	50	9·05	3140	..	53	0·65	4·07		
2·16. June 5, 1866.	"	" "	14	61	10	Charleville, Rethel	49	1·2	5	54	8·37	2610	..	53	0·86	5·30		
2·16. June 6, 1866.	"	" "	14	58	10	" "	49	1·2	5	46	7·56	2240	..	45	0·77 } 0·76	4·50 } 4·60		
2·16. June 7, 1866.	"	" "	14	62	10	" "	49	1·2	5	48 } 44	6·38	2300	..	47 } 54	0·75	4·70		3
40·35. April 2, 1866.	"	" "	12	87	14	Gretz, Nangis ..	31	0·4	5	43	8·26	1540	..	50	0·57	3·57		
2·43. June 6, 1866.	"	" "	14	68	11	Rheims, Charleville	88	0·5	10	36	6·92	4640	..	53	0·80	4·82		
1·38. July 22, 1865.	"	Free wheels. "	1	40	7	Rheims, Epernay	30	0·6	9	40	7·66	1210	..	40	1·00	5·71		
2·43. July 22, 1865.	"	Mixed. "	14	77	13	Rheims, Rethel ..	39	0	5½	41	6·64	2240	..	57	0·74	4·38		
2·16. July 20, 1865.	"	" "	14	78	12	Rethel, Rheims ..	39	0	6	42	6·28	2420	..	62	0·79	5·16		
40·35. April 24, 1866.	"	" "	12	70	12	Gretz, Nangis ..	31	0·4	5	44	12·00	2010	..	64	0·91	5·33		
40·35. April 24, 1866.	"	Mixed.—Type	12	50	8	Troyes, Bar-sur-Aube	54	1·0	6	46	7·44	2280	..	42	0·84	5·25		
31. May 4, 1865.	"	" "	7	70	12	Châlons, Blesme	45	0·9	3½	51	8·90	2915	130	64	0·91	5·33	0·49	
40·35. April 24, 1866.	"	" "	12	70	12	Paris, Nogent ..	16	0·7	5	46	10·00	1140	..	71	1·01	5·92		
40·35. April 26, 1866.	"	" "	12	76	12	Romilly, Troyes ..	38	1·0	5	51	7·94	2530	151	66	0·86	5·05	0·43	
31. May 4, 1865.	"	" "	7	70	12	Blesme, Bar ..	37	1·6	4	50	8·30	2270	169	61	0·87	5·08 } 5·34	0·38	
31. Dec. 21, 1865.	"	" "	7	73	14	" " ..	37	1·6	4	47 } 45	10·01	2590	168	70 } 64	0·95	5·00	0·41	4
40·35. April 26, 1866.	"	" "	12	87	14	Paris, Gretz ..	38	1·9	6	42	7·87	2900	..	76	0·87	5·40		
1·43. July 19, 1865.	"	Free wheels. "	1	64	10	Epernay, Rheims	30	0·6	9·25	29	3·75	1680	..	56	0·87	5·60		
31. May 4, 1865.	"	Mixed. "	7	70	12	Bar, Leronville ..	35	1·4	8	43	5·80	2480	..	71	1·01	5·92		
31. Dec. 21, 1865.	"	" "	7	73	14	Bar, Commercy ..	40	1·2	8	43	10·00	2740	..	68	0·93	4·86		
40·35. April 24, 1866.	"	Mixed.—Type	12	70	12	Nogent, Gretz ..	22	2·4	6	44 } 50	10·00	1720	168	78 } 72	1·11	6·50 } 7·43	0·46 } 0·48	5
40·35. April 24, 1866.	"	" "	12	50	8	Bar, Chaumont ..	41	3·8	6	57	8·83	2770	131	67	1·34	8·37	0·51	

TABLE XXVII.—CONSUMPTION OF WATER.—GOODS TRAINS.

Date. 1	Kind of Engine. 2	Gross Weight of the Train. 3	Extreme Stations. 4	Distance experimented over. 5	Inclination of the Line. 6	Greatest Gradient to be ascended. 7	Mean Speed an hour. 8		Resistance of the Train a ton. 9	Effective Work in horse-power. 10	Total Consumption of Water. 11	Consumption of Water: to the kilomètre. 12		Consumption of Water: a ton to the kilomètre. 13		Consumption of Water: to the effective horse-power and to the kilomètre. 14		Observations. 15
		tons.		kiloms.	mills.	mills.	kiloms.		kilogs.		litres.	litres.		litres.		litres.		
11 Jan., 1866	8 wheels coupled	533	Forbach, St. Avold	19	2·5	5	16		3·30	238	4203	221		0·41		0·92		
10 Jan., 1866	” ”	469	” ”	19	2·5	5	17		3·00	237	3620	190		0·40		0·80		
10 Jan., 1866	” ”	473	” ”	19	2·5	5	15	17	2·60	205	3870	203	198	0·43	0·40	0·99	0·84	
23 Dec., 1865	” ”	485	” ”	19	2·5	5	19		3·01	265	3380	178		0·36		0·67		Water low.
22 Dec., 1865	” ”	476	” ”	19	2·5	5	17		3·23	233	3760	198		0·41		0·84		
21 March, 1867	” ”	210	Vielsalm, Gouvy	10	15·½	18	14	16	18·05	198	1940	194	196	0·92	0·88	0·98	0·86	
22 March, 1867	” ”	233	” ”	10	15·½	18	17		18·24	263	1980	198		0·84		0·75		
20 March, 1867	Goods.—Type 20	156	Trois-Ponts, Francorchamp ..	13	17·40	19·50	11	12	20·74	134	2790	214	202	1·37	1·39	1·59	1·48	
22 March, 1867	” ” 20	135	” ”	13	17·40	19·50	13		20·40	137	2470	190		1·41		1·38		
26 July, 1864	” ” 15	170	Ay, Germaine ..	12	9·25	9·25	15		4·47	126	2797	233		1·37		1·85		Heavy rain.
21 July, 1865	” ” 20	259	Rethel, Launois	25	4·2	10	16		3·98	218	4670	187		0·72		0·86		
20 July, 1865	” ” 20	255	” ”	25	4·2	10	16	19	3·15	191	3300	132	158	0·51	0·71	0·69	0·75	
6 July, 1864	” ” 20	163	Amagne, Launois	17	6·2	10	24		6·03	235	2813	165		1·01		0·70		
20 June, 1864	” ” 20	245	Bazancourt, Witry	11	4·0	6	22		5·35	194	1630	148		0·60		0·76		
8 July, 1864	” ” 20	334	Rethel, Rheims ..	40	0	6	15		3·74	..	5707	143		0·43				
21 June, 1864	” ” 20	300	” ”	40	0	6	19	20	4·47	..	4633	116	118	0·38	0·38			
20 June, 1864	” ” 20	244	Rheims, Rethel ..	40	0	5·½	25		4·30	..	3550	84		0·34				
27 July, 1864	Mixed.—Type 14	354	” ”	40	0	6	20		3·34	..	5378	134		0·37				
1 Sept., 1864	Goods.—Type 20	316	La Vilette, Lagny	26	0·5	3·50	28		3 92	..	2230	85		0·27				
1 Sept., 1864	” ” 20	310	Lagny, Meaux ..	17	0·3	3·50	28		3·46	135	1995	117		0·37		0·87		
1 Sept., 1864	” ” 20	256	Meaux, La Ferté	21	0	5	23		3·76	140	2253	107		0·41		0·76		
31 Aug., 1864	” ” 20	301	Lagny, Noisy ..	19	0·8	3·½	28		3·40	133	2200	115		0·38		0·86		
8 July, 1864	” ” 20	333	Mohon, Rethel ..	46	1·2	6	20	26	4·64	..	5113	111	97	0·33	0·35			
6 July, 1864	” ” 20	268	Charleville, Fumay	40	0·5	5	32		6·00	210	3691	92		0·34		0·44		Speed considerable.
31 Aug., 1864	” ” 11	285	Lagny, Meaux ..	17	0·3	3·½	23		3·81	121	1642	96		0·33		0·78		
30 Aug., 1864	” ” 11	196	Château, La Ferté	30	0	0·½	26		4·50	..	2400	80		0·40				
30 Aug., 1864	” ” 11	198	La Ferté, Meaux	21	0	5	26		4·50	..	1525	72		0·36				
8 July, 1864	” ” 20	270	Deville, Mohon ..	24	0	5	25		5·50	191	3756	156		0·57		0·82		Bad weather.
14 Feb., 1865	” ” 15	185	Châlons, Epernay	31	0·4	0	37	29	6·67	160	3072	99	121	0·53	0·54	0·62		
14 Feb., 1865	” ” 15	206	” ”	31	0·4	0·4	26		6·40	135	3390	109		0·53		0·80		

TABLE XXVIII.—GREATEST PRODUCTION OF STEAM.

Kind of Engine.	Date.	Mean Speed an hour.	No. of Kilomètres experimented over.	No. of Revolutions a second.	Work exerted upon the Train.	Work to move the Engine.	Mean Total of Work.	Total Heating Surface.	Weight of Water consumed.	Weight of Water consumed to the square mètre of Heating Surface an hour.
		kiloms.			h.-p.	h.-p.	h.-p.	sq. mèt.	kilogs.	kilogs.
Crampton's ..	33. March 15, 1866	73	141	2·83	297	110	407	91·27	8680	42
Free wheels. Type 1	1·16. June 7, 1866	42	30	2·18	..	..	..	67·91	2146	42
Mixed. " 12	40·35. April 24, 1866	57	41	2·77	131	125	256	81·90	2770	38
" " 7	31. May 4, 1865	51	45	2·67	131	71	202	88·32	2915	33
" " 14	40·23. April 28, 1866	46	55	2·40	..	..	..	100·42	4264	32
" " 7	31. Dec. 21, 1865	47	37	2·45	173	66	239	88·32	2590	32
" " 12	40·35. April 24, 1866	44	22	2·14	177	68	245	81·90	1720	36
" " 12	40·35. April 26, 1866	42	38	2·05	150	65	215	81·90	2900	34
" " 12	40·35. April 26, 1866	51	38	2·47	150	79	229	81·90	2530	35
" " 12	40·35. April 24, 1866	46	16	2·22	..	..	..	81·90	1140	33
" " 14	1·68. July 27, 1864	22	40	1·05	..	..	..	100·42	5378	35
Eight coupled wheels	12·72. Jan. 11, 1866	16	19	1·13	..	..	..	193·63	4203	18
" "	E. 74. March 21, 1867	17	10	1·19	263	104	367	203·63	1980	16
Goods.—Type 20	E. 63. March 22, 1867	13	13	0·81	132	54	186	126·70	2470	20
" " 20	E. 63. March 20, 1867	12	13	0·76	140	50	190	126·70	2790	20
" " 20	1·68. July 8, 1864	25	24	1·57	190	44	234	126·70	3756	28
" " 20	1·67. July 6, 1864	24	17	1·52	236	74	310	126·70	2813	29
" " 15	78. Feb. 14, 1865	37	31	2·52	160	71	231	100·42	3072	32
" " 15	61. Feb. 14, 1865	26	31	1·77	135	50	185	100·42	3390	26
" " 15	1·67. July 26, 1864	15	12	1·02	126	53	179	100·42	2797	32
" " 11	75. Aug. 31, 1864	18	21	1·14	106	26	132	98·80	2715	22
" " 11	66. Aug. 30, 1864	26	38	1·65	148	33	181	98·80	4063	25

Of passenger engines, Crampton's developed the greatest amount of work, namely, 407 horse-power. The maximum production of steam to the square mètre of the whole heating surface was 42 kilogrammes. The mixed engine, type 12, produced a mean equal to that of the mixed engine, type 14, and yet type 12 possesses a much smaller surface. But we see from Table I. that its fire-box is as large as that of type 14, only the tubes are considerably shorter. The production of steam in passenger engines is, therefore, not sensibly increased by lengthening the tubes beyond about 3 mètres.

With respect to the wheels, the greatest production corresponds to the greatest number of revolutions a second. For Crampton's engine, to 2·83 turns correspond a production of 42 kilogrammes; for the mixed engine, type 12, to 2·77 turns correspond a production of 38 kilogrammes. The great consumption of water by the engine, type 1, is owing to the enormous quantity carried off by the steam, on account of the very small size of the boiler.

In general, for goods engines, the production to the square mètre of heating surface by the hour is less than for passenger engines. For engines with four coupled axles moving at full speed, this production was only 16 to 18 kilogrammes. These engines moved very slowly. The engine with wheels of $1^{m}\cdot 30$, moving at the rate of 37 kilomètres an hour, gave 32 kilogrammes. The engine, type 20, moving at full speed with regard to adhesion, gave a production of 20 kilogrammes. The same engine moving at full speed with regard to production, gave 29 kilogrammes, at a speed of 24 kilomètres.

The production of steam by the hour to the square mètre of heating surface, and, consequently, the work, increases with the speed of the engine. From this point of view there is, therefore, a gain in increasing the speed up to the limit that may be reached without injury to the mechanism.

Consumption of Water to the Kilomètre.—Table XXVI. gives the consumption of water to the kilomètre by various kinds of passenger engines. The mean consumption in places where the line was nearly level is the same for Crampton's as for the mixed engines, namely, about 57 litres. Upon an incline of $1^{mm}\cdot 5$ the consumption of mixed engines was 64 litres; upon an incline of 8 millimètres it was 72 litres.

Table XXVII. relates to goods trains; from this Table we see that the consumption by goods engines varied, according to the nature of the line, from 97 to 233 litres. Upon inclines of 18 and 20 millimètres, the engine (type 20) consumed more water than the engine with four coupled axles, because in the former it was necessary to force the production by closing the escape.

Consumption of Water to the Carriage or to the Ton drawn.—Tables XXVI. and XXVII. give also the consumption of water to the carriage, or to the ton drawn for each kilomètre.

1. *Passenger Trains.*—The divisions (1) and (2) of the Table relate to the same line, namely, from Paris to Epernay. It will be seen that upon this portion of line, the traction of a carriage of an express train required 7·04 litres of water, whilst a carriage of a stopping train required only 4·45 litres to the kilomètre. (Table XXVI.)

2. *Goods Trains.*—The traction of a ton, gross weight, required 0·35 litre to the kilomètre on a level in fine weather, 0·54 litre on a level in bad weather, and 1·39 litre on an incline of $19^{mm}\cdot 50$. (Table XXVII.)

The traction of a ton weight at an equal rate of speed upon portions o. line similar in nature, required 0·88 litre with an engine with eight coupled wheels, and 1·39 litre with an engine of type 20.

Engines with eight coupled wheels are, therefore, economical, as they utilize in a high degree the mechanical force of the steam. (Large boiler, long tubes.)

Consumption of Water to the Horse-power.—Other things being equal, this consumption decreases with the increase of speed. Thus, for express trains, it was 0·23 litre, and for stopping trains 0·44 litre.

In the case of a very slow goods train this consumption reached 1·48 litre, and even 1·85. These results are accounted for by the fact that in engines moving at a high rate of speed the steam is expanded more than in engines moving at a slow rate. Under the same conditions, the consumption to the horse-power and by the kilomètre was 0·86 litre for the engines with eight coupled wheels, and 1·48 litre for the engine type 20, which shows again the advantage offered by the former engines from an economical point of view.

Water carried off by the Steam and lost by Leakage.—If we compare the actual consumption of water measured in the tender with the theoretical consumption calculated from the volume described by the piston during the length of admission, we find the former much greater than the latter. This is because a large quantity of water is carried off in an unvapourized state, and some is lost by leakage. Our calculations show that this loss formed the following fractions of the total consumption;—

Train (1) 68,	June 21, 1864	.. ..	30 per cent.
„ (1) 67,	July 6, 1864	.. ..	24 „
„ (1) 68,	July 8, 1864	.. ..	31 „
„ (2) 65,	July 21, 1866	.. ..	39 „

From this we conclude that for engines of type 20, moving at nearly full speed, the waste of water is about 31 per cent. We may remark that in these examples the engines were in a good condition.

It is plain that leakage should be prevented as much as possible. But is it desirable to dry the steam? A saving of fuel would be effected; but beyond a certain degree of dryness, other and greater disadvantages would ensue. The piston, the cylinder, and the stuffing are rapidly destroyed when the steam is too dry. It has been noticed in the case of drivers who are accustomed to keep the water low, that they consume less fuel than those who prefer to keep the water high; but, on the other hand, it has been noticed again that the engines of the former get soonest out of order. The question is thus reduced to one of cost of fuel.

Note D.—Friction peculiar to an Engine at Work.—Besides the resistances which we have found for engines in motion without working, there is a certain supplementary resistance created by the reciprocal pressures of the moving parts. Supposing the engine to move slowly enough to allow us to consider the steam as acting with full pressure from the beginning of the admission, and also to consider the resisting pressure as equal to the pressure of the atmosphere, and calling

p the absolute pressure of the steam in the boiler,
p' the pressure of the atmosphere,
s the surface of the piston in square mètres,
l the length of the admission,
l' the length of the expansion,
l'' the length of clearance at the escape,
l_1 the length of the escape,
l'_1 the length of the compression,
l''_1 the length of clearance at the admission,

we have as the positive work of the gases behind the piston during a single stroke of the piston,

$$10000 \times s\left[p\,l\left(1 + 2\cdot 30 \log.\frac{l + l'}{l}\right) + p'\,l''\right].$$

The negative or resisting work of the gases in front of the piston is expressed by

$$10000 \times s\left(p'\,l_1 + p\,l''_1 \times 2\cdot 30 \log.\frac{l'_1 + l''_1}{l''_1} + p\,l''_1\right).$$

The formula expressing the work to the single stroke of the piston is, therefore,

$$\mathrm{T} = 10000\,s \times \left[p\,l\left(1 + 2\cdot 30 \log.\frac{l - l'}{l} - p'(l_1 - l'')\right) - p\,l''_1 \times 2\cdot 30 \log.\frac{l'_1 + l''_1}{l''_1} - p\,l''_1\right].$$

For the engine of type 20, with the driving lever at the 6th division, we have

$s = 0\cdot 1515$ mètre.	$l'_1 = 0\cdot 163$ mètre.
$l = 0\cdot 272$ „	$l''_1 = 0\cdot 016$ „
$l' = 0\cdot 249$ „	$p = 8\cdot 250$ kilogrammes.
$l'' = 0\cdot 136$ „	$p' = 1\cdot 033$ „
$l_1 = 0\cdot 478$ „	

Substituting these values in the preceding formula, we find T = 4500 kilogrammètres.

For one revolution of the wheels, we shall have for the two pistons, 4 × T = 18000 kilogrammètres.

If we suppose a speed of 15 kilomètres an hour, we shall have a second,

$$18000 \times \frac{4\cdot 16}{4\cdot 40} = 17000 \text{ kilogrammètres, or 226 horse-power.}$$

Now let us consider the case of the train (1) 68 of the 8th July, 1864. This train was drawn up an incline of 6 millimètres by an engine of type 20, at a speed of 15 kilomètres an hour, the driving lever standing at the 6th division, and the useful work, measured on the couplings of the first carriage, was 175 horse-power; which gives as the quantity of work absorbed by the train $175 \times 75 = 13125$ kilogrammètres. To this must be added the work absorbed by the resistances of the engine and tender, at a speed of 15 kilomètres an hour ($4^{m} \cdot 16$ a second), up an incline of 6 millimètres (16 kilogrammes a ton for the traction and the friction as mere vehicles); this work is found to be 3461 kilogrammètres.

We have, therefore,

		Kilogrammètres.
Work absorbed by the train ..	.. ..	13125
Work absorbed by the engine	.. ..	3461
	Total	16586

On the other hand, we found;—

Work produced by the steam	.. ..	17000
	Difference	414

Thus the work absorbed by the extra friction caused by the pressure of the steam was about 400 kilogrammètres. On account of the hypotheses which we have made, however, this quantity is rather above than below the truth.

The engine weighing 33 tons, the resistance due to these frictions, measured at the circumference of the wheels, was $\frac{414}{4 \cdot 16 \times 33} = 3^{k} \cdot 02$ to the ton. The whole resistance due to the friction of the mechanism and to the pressure of the steam is, therefore, $6 \cdot 05 + 3 \cdot 02 = 9 \cdot 07$. (See analysis of the various resistances in engines.) Strictly, this resistance does not apply to the circumference of the wheel, but it absorbs a portion of the pressure exerted by the steam upon the pistons.

From what we have given above, we may decompose the total amount of work in the following manner;—

175 horse-power exerted upon the couplings of the first carriage,
51 horse-power absorbed by the engine and tender.

In the case of a level way and the same speed, the disposable work upon the couplings would have been greater. The total amount of work remaining the same, it would be decomposed as follows;—

192 horse-power upon the couplings,
34 horse-power absorbed by the engine and tender.

Effective Work of a Locomotive Goods Engine.—If we call *effective work* the ratio of the useful to the theoretical work of the steam, calculated by the formula given above, we have $\frac{192}{226} = 0 \cdot 85$.

The effective work was, therefore, 85 per cent. under the circumstances of the experiment, on a level way at full traction, and moving at a slow rate of speed. But we do not consider this the proper way to define the effective work.

Influence of the Mode of Distribution on the Effective Work.—The theoretical work of the steam is that which would correspond to a fictitious distribution, one which would consume the same weight of steam that we have supposed, but which would utilize this steam perfectly. We will suppose, therefore, that the admission is of the same length as before, say 272 millimètres, but that all the remainder of the stroke, say 385 millimètres, is by expansion. The expenditure of steam would be the same at the same speed; but the theoretical work would be the maximum work corresponding to the given length of admission.

In this case the theoretical formula becomes

$$T = 10000 \times s \left[p\,l \left(1 + 2 \cdot 30 \log. \frac{l + l'}{l} \right) - p' \,(l' + l) \right].$$

If we apply this formula to the engine type 20, with the driving lever at the 6th division, we find that the theoretical work to each revolution of the wheels would be 21000 kilogrammètres. The theoretical work with Stephenson's slide-valve, in the same circumstances, being 18000 kilogrammètres to each revolution, we have $\frac{18000}{21000} = 0 \cdot 86$; which shows that the mode of distribution by means of Stephenson's slide-valve reduces, in the case in question, by 14 per cent. the useful work which might be obtained from the steam.

The actual effective work of an engine being, in our opinion, the ratio of the useful work developed upon the train, to the theoretical work of the steam corresponding to a perfect distribution, we have as the effective work of the engine in the case in question,

$$\frac{192}{\frac{21000}{75} + \frac{4 \cdot 16}{4 \cdot 00}} = \frac{192}{264} = 0 \cdot 72.$$

Effective Work of a Passenger Engine.—As an example of the amount of effective work in the case of a passenger engine, we will cite the following experiment;—

Train 32, of March 15, 1866. From Château-Thierry to Paris, a distance of 94 kilomètres.
Mean inclination of the line, nothing.
Volume of water consumed, 5670 litres.
Driving lever at the 1st division, regulator half open.
Mean useful work, 144 horse-power.
Mean speed, 45 kilomètres an hour.
Mixed engine, type 14 .. { Diameter of the cylinder, 42 centimètres. Stroke of the piston, 56 centimètres. Diameter of the driving wheels, $1^{m}\cdot 68$.
Length of the admission, on the left side of the piston, $0^{m}\cdot 095$.
" " on the right side of the piston, $0^{m}\cdot 133$.

The length of the admission not being the same on both sides of the piston, we shall make the calculation for each side.

Mean pressure indicated by the manometer = $7\frac{1}{2}$ atmospheres. The pressure may rise to 8 atmospheres; but the train being light, it did not reach its maximum.

Supposing the pressure in the boiler of $7\frac{1}{2}$ atmospheres to have existed upon the piston throughout the admission, the steam to have been expanded throughout the remainder of the stroke, and the resisting pressure throughout the whole stroke to have been equal to the atmospheric pressure the theoretical work of the steam is given by the formula

$$T = 10000 \times s\left[p\,l\left(1 + 2\cdot 30 \log. \frac{l+l'}{l}\right) - p'\,(l + l')\right].$$

We find for the left side of the piston, T = 2046 kilogrammètres; and for the right side of the piston, T = 2704 kilogrammètres. The theoretical work to each revolution of the wheels is $2\,T + 2\,T' = 9500$ kilogrammètres. But at a speed of 45 kilomètres an hour, the number of revolutions a second is $2\cdot 38$, which gives as the theoretical work a second, $9500 \times 2\cdot 38 = 22600$ kilogrammètres, or 301 horse-power. Thus the effective work was $\frac{144}{301} = 0\cdot 48$. It must be observed that the engine was not working at its maximum power.

Note E.—Dimensions of the Parts of Engines.—The formulæ which we have already given enable us to calculate the heating surface and the adhesive weight. It now remains for us to fix the dimensions of the principal parts. Our experiments lead to the following results;—

Fire-box.—The surface of the fire-box ought to be not less than;—from 6 to 8 square mètres, for a total heating surface of 80 to 150 square mètres; from 9 to 10 square mètres, for a total heating surface of 150 to 200 square mètres.

Cylinders.—The diameter of the cylinders will be from

38 to 40 centimètres for engines with free wheels,
40 " 42 " for mixed engines,
42 " 45 " for engines with 6 wheels coupled,
48 " 50 " for engines with 8 wheels coupled.

Large cylinders give great power to start a load, but they use a large quantity of steam when in motion. In every case their diameter will be fixed by these two considerations.

Wheels.—The diameter of the wheels should be sufficiently great to prevent a too high rate of speed in the oscillating parts. The heavier the mechanism, the lower will be the limit of this speed. We recommend the following limits (whence result the maximum number of revolutions a second);—

2 to $2^{m}\cdot 30$ for express engines, free wheels,
($V = 80^{k}$) $3\cdot 5$ to $3\cdot 1$ revolutions a second;
$1\cdot 60$ to $1^{m}\cdot 80$ for passenger mixed engines,
($V = 55^{k}$) $2\cdot 8$ to $2\cdot 7$ revolutions a second;
$1^{m}\cdot 40$ for goods engines to be used on a level,
($V = 30^{k}$) $1\cdot 9$ revolution a second;
$1\cdot 20$ to $1^{m}\cdot 30$ for goods engines to be used on steep gradients,
($V = 24^{k}$) $1\cdot 7$ to $1\cdot 6$ revolution a second.

Note F.—Power of Brakes.—A few observations on the action of brakes may be added to the remarks we have already made on the subject of the resistance of *any vehicle* running upon a railway.

Usually, brakes are applied so as to stop the wheels altogether, that is, the wheels are made to slide upon the rails while remaining motionless relatively to the vehicle; usually also, the brake-blocks are of wood, and of that kind of wood which offers the greatest friction, in order to reduce the force applied to them. When the action of the brakes is continued for any considerable length of time, that portion of the wheel which is in contact with the rail is worn away, thereby causing a flat surface in the tire of the wheel, and the wooden blocks are quickly destroyed. To remove these two defects, it has been proposed to allow the wheels to revolve slowly in contact with the brake-blocks, and to substitute iron for wooden blocks. The question is whether this change would reduce the useful effect of the brakes. For the purpose of solving this important question, the following experiments were undertaken. Two trains were made up of an engine, the dynamometer car, and a brake-van. The brake-van of the first train was provided with wooden brake-blocks; in the second train, a van with cast-iron blocks was substituted for it.

The two series of experiments were made upon the same piece of line, when the rails were

quite dry. A determinate speed was kept for a certain time, then, at a given signal, the steam was shut off; at the same instant the brakes were applied and the train left till it came to a stand. By means of the dynamometer car the distance, the speed, and the resistance offered by the brake-van were accurately measured. Another mode of experimenting consisted in applying the brakes while the engine continued to draw, keeping up during the time of the experiment a uniform speed.

TABLE XXIX.—EXPERIMENTS ON THE POWER OF BRAKES.

Nature of the Brake.	Numbers of the Experiments.	Speed kept up.	Speed when the Steam was shut off.	Sliding on the Rails.	Distance Run while Stopping.	Mean Resistance of the Brake.	Observations.
		kiloms.	kiloms.		mètres.	kilogs.	
Wooden blocks.	1	..	46	Complete	550	760	The sliding is *complete* when the wheels are fixed, *partial* when they turn slowly.
	2	..	42	"	450	740	
	3	..	45	"	630	625	
	4	..	55	"	830	740	
	5	..	39	"	295	830	Weight of the brake with wooden blocks, 6398 kilogrammes.
	6	..	41	"	394	850	
	7	29	..	"	..	980	
	8	38	..	"	..	810	
	9	33	..	"	..	960	
	10	41	..	"	..	880	
				Mean resistance ..		817	
Cast-iron blocks.	1		36	Partial	262	1030	Weight of the brake with iron blocks, 5730 kilogrammes.
	2	..	36	"	317	950	
	3	..	32	"	210	1050	
	4	..	64	"	960	985	
	5	..	44	"	358	1110	
	6	..	47	"	595	910	
	7	..	33	"	315	985	
	8	37	..	"	..	1140	
	9	34	..	"	..	1030	
	10	31	..	"	..	1390	
	11	36	..	"	..	1080	
	12	26	..	"	..	1320	
	13	32	..	"	..	1220	
	14	64	..	"	..	260	
	15	36	..	"	..	1400	
	16	43	..	"	..	1340	
	17	30	..	"	..	1400	
	18	43	..	"	..	1200	
	19	47	..	"	..	1000	
	20	28	..	"	..	1340	
	21	33	..	"	..	1100	
				Mean resistance ..		1100	

Table XXIX. gives the results of these experiments. The mean speed is the same in both series. The resistance of the brakes provided with wooden blocks, when the wheels were prevented from revolving at all, was 817 kilogrammes, while that of the brake furnished with cast-iron blocks, when the wheels were made to revolve slowly, was 1100 kilogrammes. Referring these resistances to the weight of the corresponding brake-van, we find them equal to

0·128 of the weight for the brake with fixed wheels,
0·192 of the weight for the brake with wheels turning slowly.

Thus, a considerably greater effect can be obtained from a brake, by allowing the wheels to turn slowly than by stopping them altogether.

From a theoretical point of view, this fact may be explained in the following way;—

Let W be the weight of the brake-van; s the distance run from the moment when the wheels are stopped till the train is brought to a standstill, and f the coefficient of friction of the tire on the rail.

The negative work of the brake will be expressed by $W \times f \times s$.

Again, let f' be the coefficient of friction of the tire which turns slowly, and s' the distance traversed by a point of the tire, relatively to the rail, during the whole of the time occupied in stopping.

The negative work of the brake will be expressed by $W \times f' \times s'$.

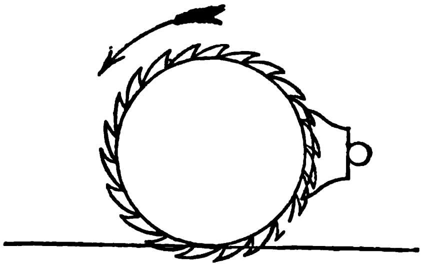
If the initial *vis viva* is the same in both cases, we shall have $W f s = W f' s'$. But we have $s < s$. Therefore, f' must be greater than f.

The excess of f' over f may be thus explained.

The effect of the friction of the wheel against the brake-block is to bring the exterior molecules of the tire into the position represented by Fig. 2613.

This position of the molecules is reversed at each revolution by the friction caused by the sliding on the rails. These two frictions in contrary directions, increase each other in a marked degree.

2613.

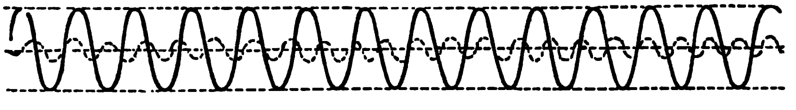


But when the wheel is fixed, a small flat face is formed upon which the sliding is effected with greater facility. These hypotheses are confirmed by practice. As a matter of fact, the tires which rub against the iron blocks are worn out in a short time, without in any degree destroying their circular form.

We must remark that the resistance of brakes increases as the speed diminishes. This fact is shown by Table XXIX., and especially by the form which the curves of the diagrams assume. We perfectly agree on this subject with M. Bochet, whose experiments are discussed in the Annales des Mines.

Note G.—Lowest Limit to the Speed of Trains.—The study of our dynamometrical curves has convinced us that it is not advantageous to reduce the speed of goods trains to a very low rate, even where the gradients are steep. So long as the train moves at a pretty good speed, the oscillations of the dynamometrical curve are inconsiderable, as shown by the dotted line in Fig. 2614; the train being in this case kept steady by the *vis viva* which it has stored up; but if the train moves very slowly, the oscillations of the curve become great, as shown by the full line.

2614.



In this case, the upper and lower limits *b b*, *c c*, of the oscillations diverge widely from the line *a a*, representing the mean tractive force; this force does not sensibly change so long as a speed of 20 kilomètres an hour is not exceeded. We see, therefore, that a very low rate of speed, the effect of which is to raise the upper limit *b b*, would require greater forces for the same mean traction. Consequently there will be greater risk of slipping. Besides, the production of steam becomes difficult when the speed is very low. For these reasons, we think that the lowest limit of the speed of trains should be fixed at 12 kilomètres an hour.

Note H.—Resistance of Engines without Tenders.—The resistances of engines may be considered as composed of three elements;—

1. Resistances due to the motion of the engine considered as a mere vehicle;
2. Resistances due to the friction of the mechanism;
3. Resistances due to the additional friction caused by the pressure of the steam.

For goods engines with three coupled axles, we found, to the ton;—

For the resistances due to the first	$6^k \cdot 15$
" " " second	$6^k \cdot 05$
" " " third	$3^k \cdot 02$
Total	$15^k \cdot 22$

The total resistance to the ton for a goods engine is, therefore, $15^k \cdot 22$. It will be noticed that the resistance due to the second cause is nearly equal that due to the first.

We were unable to determine the third element in the case of mixed engines with free wheels, because at the usual speed of those engines we could not make the hypothesis on which we calculated goods engines. There is reason to believe, however, that in this kind of engine, the additional resistances due to the pressure of the steam do not exceed those found for goods engines, and that further, they are about equal to these latter. Admitting this, we shall have approximatively;—

Passenger Engines (Free Wheels).

1. For the resistances due to the first cause..	$3^k \cdot 00$
2. " " " second "	$2^k \cdot 00$
3. " " " third "	$3^k \cdot 00$
Total resistance a ton	$8^k \cdot 00$

Mixed Engines.

1. For the resistances due to the first cause..	$5^k \cdot 22$
2. " " " second "	$4^k \cdot 38$
3. " " " third "	$3^k \cdot 00$
Total resistance a ton	$12^k \cdot 60$

TABLE A.—EXPERIMENTS ON THE RESISTANCE OF GOODS TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmosphere.	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations.
				tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
1	141. April 11, 1862	6 wheels, 30 tons	7	196	30	..	..	Incline 9·25	800	+15	Calm and dry ..	15	2780	14·20	4·95	
2	143. April 12, 1862	6 ,, 30 ,,	7	171	21	..	..	,, 9·25	800	+15	Opposing wind ..	19	2820	16·50	7·25	
3	562. June 12, 1862	6 ,, 27 ,,	7	215	26	..	..	,, 6·00	1500	+23	Calm and dry ..	19	1970	9·10	3·10	
4	567. June 27, 1862	6 ,, 27 ,,	9	221	27	..	..	,, 1·60	1000	+22	,, ,, ..	29	1330	6·03	4·43	
5	567. June 27, 1862	6 ,, 27 ,,	9	222	30	..	..	,, 4·40	3000	+22	,, ,, ..	23	1870	8·43	4·03	
6	563. June 14, 1862	6 ,, 27 ,,	6	238	34	..	..	,, 2·00	2000	+15	Slight wind ..	24	1560	6·55	4·55	
7	563. June 14, 1862	6 ,, 27 ,,	8	221	32	..	..	,, 0·40	1500	+15	,, ,, ..	33	1140	5·16	4·76	
8	563. June 14, 1862	6 ,, 27 ,,	7	242	35	..	..	,, 1·15	800	+15	,, ,, ..	31	1300	5·34	4·19	
9	199. June 20, 1862	6 ,, 30 ,,	8	446	42	..	..	Level ..	Straight	+14	Damp	32	1800	3·73	3·73	Double traction.
10	199. June 20, 1862	6 ,, 30 ,,	6	567	53	..	..	Incline 1·81	2000	+14	,, ...	20	2800	4·93	3·12	
11	199. June 20, 1862	6 ,, 30 ,,	18	490	42	..	..	,, 1·80	800	+14	,, ...	28	2370	4·76	2·96	,, ,,
12	199. June 20, 1862	6 ,, 30 ,,	6	212	23	..	..	,, 3·62	800	+14	,, ...	31	1370	6·82	3·20	,, ,,
13	199. June 20, 1862	6 ,, 30 ,,	7	265	27	..	..	,, 5·50	1200	+14	,, ...	22	2500	9·25	3·75	
14	565. June 11, 1862	6 ,, 27 ,,	8	223	36	..	..	,, 6·00	1200	+	,, ...	21	2240	10·00	4·00	
15	562. June 15, 1862	6 ,, 27 ,,	7	301	33	..	..	,, 0·44	1500	+20	Calm and dry ..	29	1170	3·88	4·32	
16	562. June 15, 1862	6 ,, 27 ,,	7	241	27	..	..	,, 6·00	1500	+20	,, ,, ..	22	2240	9·28	3·28	
17	564. June 24, 1862	6 ,, 30 ,,	10	180	30	..	..	,, 3·54	800	+18	Light dry wind ..	24	1540	8·60	5·06	
18	564. June 24, 1862	6 ,, 30 ,,	8	210	41	..	..	,, 4·17	1000	+18	,, ,, ..	20	1920	9·33	5·16	
19	564. June 24, 1862	6 ,, 30 ,,	5	210	41	..	..	,, 0·60	1000	+18	,, ,, ..	28	1230	5·85	6·45	
20	562. June 25, 1862	6 ,, 30 ,,	10	196	28	..	..	,, 1·08	1000	+22	Slight rain ..	28	1460	7·08	6·00	
21	562. June 25, 1862	6 ,, 30 ,,	5	193	28	..	..	,, 5·50	1000	+22	,, ,, ..	20	2216	11·20	5·70	
22	563. June 24, 1862	6 ,, 30 ,,	6	173	23	..	..	,, 6·00	1000	+23	Fair	22	1720	9·90	3·90	
23	142. Nov. 23, 1862	6 ,, 30 ,,	5	176	29	20	7	,, 9·00	1000	+ 4	Calm and dry ..	16	2700	15·30	6·30	Double traction.
24	142. Nov. 24, 1862	6 ,, 30 ,,	6	216	48	33	2	,, 9·00	1000	+ 5	,, ,, ..	23	3780	17·50	8·50	
25	139. Nov. 23, 1862	6 ,, 30 ,,	6	167	22	40	10	,, 9·25	800	+ 4	Calm, foggy ..	18	2580	15·45	6·20	
26	139. Nov. 24, 1862	6 ,, 30 ,,	9	151	23	22	5	,, 9·25	800	+ 3	Calm and dry ..	18	2540	16·80	7·55	
27	85. Nov. 26, 1862	6 ,, 27 ,,	3	207	33	26	13	,, 5·00	720	+ 5	Fair	17	2190	10·52	5·52	
28	85. Nov. 26, 1862	6 ,, 27 ,,	29	207	33	26	13	Level ..	1000	+ 5	,, ...	30	1180	5·70	5·70	
29	85. Nov. 26, 1862	6 ,, 27 ,,	6	207	33	26	13	Incline 0·32	1400	+ 5	,, ...	26	1310	6·32	6·00	
30	85. Nov. 26, 1862	6 ,, 27 ,,	7	207	33	26	13	Level ..	1000	+ 5	,, ...	29	1220	5·89	5·89	
31	77. Dec. 6, 1862	6 ,, 27 ,,	3	189	30	18	..	,, ..	1000	+12	,, ...	32	983	5·20	5·20	
32	77. Dec. 6, 1862	6 ,, 27 ,,	22	172	28	18	..	,, ..	1000	+12	,, ...	26	980	5·70	5·70	
33	64. Mar. 19, 1863	6 ,, 30 ,,	31	321	29	50	14	Incline 0·18	1000	+ 6	,, ...	28	1230	3·83	4·01	
34	140. Mar. 21, 1863	6 ,, 30 ,,	6	211	29	0	7	,, 9·00	1000	+ 7	Rain, slight wind	17	2830	13·40	4·40	Frequent slippings.
35	140. Mar. 21, 1863	6 ,, 30 ,,	4	211	29	0	7	,, 5·00	Straight	+ 7	,, ,,	24	1960	9·29	4·29	Through a tunnel.
36	85. Feb. 27, 1863	6 ,, 30 ,,	18	249	37	30	3	,, 0·40	1500	+ 2	Calm, rather foggy	25	1320	5·28	4·88	
37	85. Feb. 27, 1863	6 ,, 30 ,,	14	267	39	30	3	,, 0·55	1000	+ 1	,, ,,	27	1580	5·92	5·37	
38	85. Feb. 27, 1863	6 ,, 30 ,,	9	267	41	27	3	,, 1·40	1000	+ 1	,, ,,	22	1800	6·75	5·35	
39	62. Feb. 27, 1863	6 ,, 30 ,,	10	306	28	..	..	,, 0·70	1500	+13	Fair	31	880	2·88	3·58	Many trucks.
	Carried forward		359													

TABLE B.—EXPERIMENTS ON THE RESISTANCE OF GOODS TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmosphere.	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations
	Brought forward		359	tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
40	62. Feb. 27, 1863	6 wheels, 30 tons	10	306	28	..	..	Incline 0·40	1000	+13	Fair	25	840	2·74	3·14	Many trucks.
41	62. Feb. 27, 1863	6 „ 30 „	11	322	30	..	..	„ 0·40	1500	+13	„	27	980	3·04	3·44	
42	62. Feb. 27, 1863	6 „ 30 „	9	322	30	..	..	„ 0·40	Straight	+13	„	31	820	2·54	2·94	
43	85. Feb. 22, 1863	6 „ 30 „	8	281	37	16	..	„ 0·40	„	+ 3	Calm, rather foggy	26	1430	5·09	4·69	
44	85. Feb. 22, 1863	6 „ 30 „	12	281	37	16	..	„ 0·40	1500	+ 3	„ „	25	1450	5·16	4·76	
45	85. Feb. 22, 1863	6 „ 30 „	9	281	37	16	..	„ 0·40	1000	+ 2	„ „	25	1580	5·63	5·23	
46	85. Feb. 22, 1863	6 „ 30 „	10	281	37	16	..	„ 0·70	Straight	+ 1	„ „	25	1570	5·58	4·88	
47	39. Feb. 20, 1863	6 „ 30 „	4	166	23	..	..	„ 9·25	800	+ 0	Calm and dry ..	11	2640	15·90	6·65	
48	83. March 16, 1864	6 „ 30 „	11	196	29	31	7	Level ..	1200	+ 6	„ „ ..	22	980	5·00	5·00	
49	83. March 16, 1864	6 „ 30 „	6	196	29	31	7	Incline 0·50	1000	+ 6	„ „ ..	26	910	4·64	5·14	
50	83. March 16, 1864	6 „ 30 „	7	279	37	25	5	Level ..	2000	+ 9	„ „ ..	33	1130	4·12	4·12	
51	91. March 16, 1864	6 „ 30 „	9	160	25	..	..	Incline 0·40	Straight	+ 2	Dry, contrary wind	29	1200	7·50	7·10	
52	91. March 17, 1864	6 „ 30 „	8	160	25	..	..	„ 0·40	1500	+ 2	„ „	28	1230	7·67	7·27	
53	91. March 17, 1864	6 „ 30 „	5	169	26	..	..	„ 0·40	1000	+ 5	„ „	24	1240	7·33	6·93	
54	91. March 17, 1864	6 „ 30 „	6	169	26	..	..	„ 0·70	Straight	+ 5	„ „	25	1420	8·38	7·68	
55	91. March 17, 1864	6 „ 30 „	7	160	25	..	..	„ 1·50	„	+ 8	„ „	30	1500	9·37	7·87	
56	78. March 17, 1864	6 „ 30 „	5	478	47	..	..	„ 1·00	„	+14	Dry	29	1830	3·82	4·82	Double traction, many trucks.
57	78. March 17, 1864	6 „ 30 „	8	478	47	..	..	„ 0·70	„	+14	„	29	1910	3·98	4·68	
58	78. March 17, 1864	6 „ 30 „	10	474	46	..	..	„ 0·40	1500	+14	„	31	1700	3·58	3·98	
59	78. March 17, 1864	6 „ 30 „	8	474	46	..	..	„ 0·40	Straight	+14	„	33	1410	2·98	3·38	
60	88. March 18, 1864	6 „ 30 „	10	249	26	45	..	„ 0·70	1500	+12	Dry, windy ..	29	825	3·35	4·05	
61	88. March 18, 1864	6 „ 30 „	4	249	26	45	..	„ 0·40	1000	+10	„ „ ..	32	1050	4·22	4·62	
62	88. March 18, 1864	6 „ 89 „	13	241	29	40	..	„ 0·40	1500	+ 8	„ „ ..	30	940	3·90	4·30	
63	89. March 18, 1864	6 „ 30 „	9	264	38	30	8	„ 0·40	Straight	+11	„ „ ..	28	1370	5·19	4·79	
64	89. March 18, 1864	6 „ 30 „	8	264	38	30	8	„ 0·20	1000	+11	„ „ ..	18	1625	6·14	5·94	
65	89. March 18, 1864	6 „ 30 „	5	264	38	30	8	„ 0·70	Straight	+11	„ „ ..	26	1750	6·62	5·92	
66	89. March 18, 1864	6 „ 30 „	7	258	37	30	8	„ 1·50	„	+11	„ „ ..	32	1980	7·65	6·15	
67	89. March 18, 1864	6 „ 30 „	11	254	36	30	8	„ 2·90	1000	+11	„ „ ..	21	1970	7·16	4·26	
68	83. April 6, 1864	6 „ 30 „	6	298	51	40	..	„ 0·20	2000	+	.. ..	31	1570	5·26	5·06	
69	83. April 6, 1864	6 „ 30 „	5	244	44	40	..	Level ..	1000	+	.. ..	26	1200	4·93	4·93	
70	83. April 6, 1864	6 „ 30 „	13	226	41	40	..	„ ..	1200	+	.. ..	25	1180	5·24	5·24	
71	66. April 7, 1864	6 „ 33 „	16	329	34	60	..	„ ..	1000	+	Slight wind, dry	24	1530	4·68	4·68	
72	81. April 11, 1864	6 „ 33 „	19	254	43	30	5	„ ..	1000	+12	Fair	25	1380	5·43	5·43	
73	81. April 11, 1864	6 „ 33 „	29	254	43	30	5	Incline 0·20	1000	+12	„	23	1456	5·73	5·53	
74	78. April 12, 1864	6 „ 30 „	10	300	28	71	3	„ 0·30	2000	+12	„	32	1215	4·03	4·33	
75	78. April 12, 1864	6 „ 30 „	16	326	30	71	3	„ 0·20	1000	+18	„	29	1090	3·34	3·54	
76	91. April 13, 1864	6 „ 30 „	7	338	40	..	..	„ 0·40	Straight	+ 7	Dry, windy ..	28	1750	5·18	4·78	
	Carried forward		710													

TABLE C.—EXPERIMENTS ON THE RESISTANCE OF GOODS TRAINS.

No	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilometres.	Gross Weight of Trains.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmosphere.	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations.
	Brought forward		710	tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
77	91. Apr. 13, 1864	6 wheels, 30 tons	8	338	40	..	..	Incline 0·40	1500	+10	Dry, windy ..	27	1880	5·54	5·14	
78	91. Apr. 13, 1864	6 ,, 30 ,,	3	323	38	..	..	Level ..	1000	+10	,, ,, ..	26	1920	5·92	5·92	
79	91. Apr. 13, 1864	6 ,, 30 ,,	5	323	38	..	..	Incline 0·40	1000	+10	,, ,, ..	27	1880	5·80	5·40	
80	91. Apr. 13, 1864	6 ,, 30 ,,	7	323	38	..	..	,, 0·70	Straight	+12	,, ,, ..	28	2130	6·59	5·89	
81	91. Apr. 13, 1864	6 ,, 30 ,,	14	323	38	..	..	,, 1·35	1500	+16	,, ,, ..	27	2190	6·75	5·40	
82	78. Apr. 13, 1864	6 ,, 30 ,,	4	534	55	40	..	,, 0·70	Straight	+19	,, ,, ..	23	1850	3·45	4·15	Double traction.
83	78. Apr. 13, 1864	6 ,, 30 ,,	4	543	56	40	..	,, 0·40	1000	+19	,, ,, ..	24	1960	3·60	4·00	,, ,,
84	78. Apr. 13, 1864	6 ,, 30 ,,	7	536	55	36	..	,, 0·40	1500	+19	,, ,, ..	31	2150	4·01	4·41	,, ,,
85	78. Apr. 13, 1864	6 ,, 30 ,,	11	536	55	36	..	,, 0·40	Straight	+19	,, ,, ..	31	1690	3·14	3·54	,,
86	89. Apr. 14, 1864	6 ,, 30 ,,	10	240	44	66	9	,, 0·40	,,	+ 8	Dry, strong wind	30	1545	6·43	6·03	
87	89. Apr. 14, 1864	6 ,, 30 ,,	6	240	44	66	9	,, 0·40	1500	+ 8	,, ,,	27	1590	6·60	6·20	
88	89. Apr. 14, 1864	6 ,, 30 ,,	8	267	48	66	9	Level ..	1000	+10	,, ,,	20	2070	7·73	7·73	
89	89. Apr. 14, 1864	6 ,, 30 ,,	8	267	48	66	9	Incline 0·40	1000	+10	,, ,,	27	2135	8·00	7·60	
90	89. Apr. 14, 1864	6 ,, 30 ,,	6	245	45	66	9	,, 0·70	Straight	+10	,, ,,	26	2000	8·16	7·46	
91	89. Apr. 14, 1864	6 ,, 30 ,,	4	245	45	66	9	,, 1·70	10000	+12	,, ,,	28	2090	8·53	6·83	
92	89. Apr. 14, 1864	6 ,, 30 ,,	12	227	42	66	9	,, 3·13	1000	+14	,, ,,	21	2680	11·73	8·60	
93	89. Apr. 14, 1864	6 ,, 30 ,,	4	199	39	66	9	,, 2·70	1000	+18	,, ,,	31	2400	10·60	7·90	
94	88. Apr. 14, 1864	6 ,, 30 ,,	3	322	38	20	..	Level ..	1500	+19	Dry, windy ..	25	1330	4·13	4·13	
95	88. Apr. 14, 1864	6 ,, 30 ,,	10	310	35	20	..	Incline 0·70	Straight	+15	,, ,, ..	26	1135	3·65	4·35	
96	88. Apr. 14, 1864	6 ,, 30 ,,	6	310	35	40	..	,, 0·40	1000	+12	,, ,, ..	25	1270	4·08	4·48	
97	88. Apr. 14, 1864	6 ,, 30 ,,	12	322	38	20	..	,, 0·40	1500	+ 6	,, ,, ..	26	1360	4·23	4·63	
98	66. Apr. 15, 1864	6 ,, 33 ,,	4	272	30	50	..	,, 0·40	Straight	+20	Fair	40	1115	4·08	4·48	
99	66. Apr. 15, 1864	6 ,, 33 ,,	2	377	40	50	..	,, 3·50	2000	+20	,, ...	22	2490	6·57	3·07	
100	40·69. Apr. 28, 1864	6 ,, 27 ,,	6	278	35	33	8	,, 5·70	1200	+20	,, ...	23	2430	8·74	3·04	
101	40·69. Apr. 28, 1864	6 ,, 27 ,,	3	285	37	33	8	,, 0·80	Straight	+20	,, ...	33	1350	4·73	3·93	
102	40·69. Apr. 28, 1864	6 ,, 27 ,,	7	509	60	..	..	,, 0·20	1000	+18	.. ..	26	1525	3·00	3·20	Double traction.
103	40·69. Apr. 29, 1864	Mixed, 22 ,,	6	184	31	..	..	,, 5·70	1200	..	.. ..	17	1580	8·55	2·85	
104	40·69. Apr. 29, 1864	,, 22 ,,	4	184	31	..	..	,, 0·34	Straight	..	.. ..	24	940	5·11	4·77	
105	81. June 17, 1864	6 wheels, 33 ,,	4	336	55	27	..	,, 0·48	1000	+21	Fair	17	1230	3·65	3·22	
106	81. June 17, 1864	6 ,, 33 ,,	2	327	54	27	..	,, 3·50	1000	+21	,, ...	10	2115	6·45	2·95	
107	1·67. June 20, 1864	6 ,, 30 ,,	9	334	46	39	11	,, 9·25	800	..	,, ...	20	4480	13·45	4·20	Double traction.
108	2·67. June 20, 1864	6 ,, 33 ,,	5	271	38	47	..	,, 5·50	2000	+25	Dry, slight wind	20	2560	9·45	3·95	
109	2·67. June 20, 1864	6 ,, 33 ,,	4	232	35	50	..	,, 5·50	1500	+25	,, ,,	26	2330	10·00	4·50	
110	2·67. June 20, 1864	6 ,, 33 ,,	4	228	35	50	..	,, 3·00	800	+25	,, ,,	28	1710	7·44	4·44	
111	2·68. June 20, 1864	6 ,, 33 ,,	5	325	36	40	8	,, 5·70	700	..	Dry	20	3340	9·87	4·17	
112	2·68. June 20, 1864	6 ,, 33 ,,	9	270	32	40	8	,, 5·66	1500	..	,, ...	19	2725	10·09	4·43	
113	2·68. June 21, 1864	6 ,, 33 ,,	11	300	32	60	15	,, 5·66	700	..	.. ..	17	3040	10·13	4·47	
114	3·64. June 22, 1864	6 ,, 33 ,,	7	318	50	50	..	,, 1·50	..	..	.. ..	26	1660	5·20	3·70	
	Carried forward		949													

TABLE D.—EXPERIMENTS ON THE RESISTANCE OF GOODS TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmosphere.	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations.
	Brought forward		949	tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
115	3·64. June 22, 1864	6 wheels, 33 tons	2	309	49	50	..	Incline 4·50	..	..	Slight wind ..	19	2410	7·82	3·12	
116	3·64. June 22, 1864	6 " 33 "	3	309	49	50	..	Level ..	..	..	" " ..	24	1490	4·82	4·82	
117	3·64. June 22, 1864	6 " 33 "	7	306	48	50	..	Incline 5·00	..	..	.. ..	22	2705	8·84	3·84	
118	2·75. July 5, 1864	6 " 33 "	8	303	50	25	..	" 5·50	1500	+12	.. ..	18	2855	9·42	3·92	
119	2·75. July 5, 1864	6 " 33 "	4	303	50	25	..	" 3·00	800	+12	.. ..	22	2205	7·26	4·29	
120	2·67. July 6, 1864	6 " 33 "	8	163	25	33	12	" 10·00	1000	+16	Strong wind ..	24	2460	15·09	5·09	
121	2·67. July 6, 1864	6 " 33 "	3	268	40	20	8	" 0·20	500	+16	" " ..	39	1560	5·80	6·00	
122	2·67. July 6, 1864	6 " 33 "	6	267	43	20	8	" 0·50	500	+16	" " ..	32	1480	5·52	6·02	
123	2·70. July 7, 1864	6 " 33 "	3	362	30	33	13	" 2·40	500	..	Rain, slight wind	25	2190	5·58	3·18	
124	2·70. July 7, 1864	6 " 33 "	10	362	30	33	13	" 1·40	500	..	Slight wind ..	29	1890	5·23	3·83	
125	2·70. July 7, 1864	6 " 33 "	3	362	30	33	13	" 3·50	500	..	" " ..	21	2670	7·10	3·60	
126	2·70. July 7, 1864	6 " 33 "	3	362	30	33	13	" 0·90	500	..	" " ..	31	1470	3·90	3·00	
127	2·68. July 8, 1864	6 " 33 "	3	295	29	50	6	" 2·40	500	..	Strong wind ..	23	2330	7·92	5·52	
128	2·68. July 8, 1864	6 " 33 "	3	240	33	50	6	" 2·80	500	..	" " ..	23	2070	7·80	5·00	
129	2·68. July 8, 1864	6 " 33 "	4	247	32	50	6	" 0·20	500	..	" " ..	33	1780	6·20	6·00	
130	2·68. July 8, 1864	6 " 33 "	6	301	33	50	6	" 1·89	1000	..	" " ..	23	2160	7·20	5·31	
131	2·68. July 8, 1864	6 " 33 "	5	330	34	50	6	" 4·00	1000	..	" " ..	18	2730	8·32	4·32	
132	2·68. July 8, 1864	6 " 33 "	2	340	35	50	6	" 5·00	1000	..	" " ..	13	3110	9·15	4·15	
133	2·68. July 8, 1864	6 " 33 "	3	368	37	50	6	" 3·00	Straight	..	" " ..	25	2540	6·88	3·88	
134	2·68. July 8, 1864	6 " 33 "	16	334	35	50	6	" 5·70	700	..	" " ..	15	3150	9·44	3·74	
135	2·67. July 26, 1864	6 " 33 "	6	152	27	33	15	" 10·00	1000	..	" " ..	22	2460	16·25	6·25	
136	2·67. July 26, 1864	6 " 33 "	4	164	30	33	15	" 10·00	1000	..	" " ..	21	2590	15·75	5·75	
137	1·67. July 26, 1864	6 " 30 "	6	170	28	18	..	" 9·25	800	..	Calm, rain ..	15	2335	13·72	4·47	
138	2·68. July 27, 1864	Mixed, 20 "	10	261	31	..	..	" 5·66	700	..	Calm and dry ..	20	2350	9·00	3·34	
139	(1) 68. July 27, 1864	6 wheels, 30 "	6	317	40	..	..	" 9·00	1000	..	" " ..	15	3930	12·35	3·35	Double traction.
140	(1) 68. July 27, 1864	6 " 30 "	2	317	40	..	..	" 5·00	Straight	..	" " ..	23	2760	8·76	3·76	Double traction, through a tunnel.
141	66. Aug. 30, 1864	6 " 27 "	6	242	32	33	7	Level ..	2000	+26	Slight wind, dry	28	1055	4·36	4·36	
142	66. Aug. 30, 1864	6 " 27 "	2	238	31	33	7	Incline 3·50	Straight	+26	" " "	27	1850	7·80	4·30	
143	75. Aug. 31, 1864	6 " 27 "	12	307	42	14	7	" 0·80	1000	+20	" " "	20	1535	4·99	4·19	
144	75. Aug. 31, 1864	6 " 27 "	3	307	42	14	7	Level ..	2000	+20	" " "	27	1180	3·83	3·83	
145	75. Aug. 31, 1864	6 " 27 "	3	297	41	14	7	" ..	1000	+20	" " "	14	2270	7·65	4·15	
146	75. Aug. 31, 1864	6 " 27 "	4	273	40	14	7	Incline 0·20	1000	+20	" " "	30	987	3·61	3·41	
147	75. Aug. 31, 1864	6 " 27 "	6	279	43	14	7	" 5·00	1000	+20	" " "	12	2410	8·64	3·64	
148	75. Aug. 31, 1864	6 " 27 "	4	264	41	14	7	Level ..	1000	+20	" " "	21	1200	5·54	4·54	
149	66. Aug. 31, 1864	6 " 33 "	5	332	34	25	11	" ..	1000	..	Dry	25	1340	4·03	4·03	
150	66. Aug. 31, 1864	6 " 33 "	6	332	34	25	11	Incline 2·50	1000	..	"	17	1880	5·64	3·14	
151	63. Aug. 31, 1864	6 " 33 "	2	296	32	25	11	Level ..	1000	..	"	30	1100	3·71	3·71	
152	66. Aug. 31, 1864	6 " 33 "	2	301	32	25	11	Incline 3·50	2000	..	"	19	1860	6·15	2·65	
	Carried forward		1140													

TABLE E.—EXPERIMENTS ON THE RESISTANCE OF GOODS TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmosphere.	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations.
	Brought forward		1140	tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
153	81. Sept. 1, 1864	6 wheels, 33 tons	6	318	52	40	7	Incline 0·45	1000	+25	Calm and dry ..	29	1450	4·19	3·74	
154	81. Sept. 1, 1864	6 " 33 "	2	321	51	40	7	" 3·50	1000	+25	" " ..	15	2130	6·65	3·15	
155	81. Sept. 1, 1864	6 " 33 "	2	299	49	40	7	" 0·20	1000	+25	" " ..	34	1190	4·54	4·34	
156	81. Sept. 1, 1864	6 " 33 "	2	271	46	40	7	" 5·00	Straight	+25	" " ..	16	2200	8·10	3·10	
157	75. Feb. 13, 1865	6 " 30 "	12	175	38	80	25	" 0·40	1500	− 3	" " ..	33	1345	7·67	7·27	
158	88. Feb. 13, 1865	6 " 30 "	12	216	25	..	..	" 0·40	1500	− 2	" " ..	31	1120	5·18	5·58	
159	88. Feb. 13, 1865	6 " 30 "	10	216	25	..	..	" 0·40	Straight	− 2	" " ..	33	954	4·40	4·80	
160	61. Feb. 14, 1865	6 " 30 "	5	206	39	65	10	" 0·40	"	− 3	" " ..	26	1402	6·80	6·40	
161	78. Feb. 14, 1865	6 " 30 "	9	185	22	35	10	" 0·40	1500	− 1	Dry, slight wind	37	1240	6·65	7·05	
162	78. Feb. 14, 1865	6 " 30 "	10	185	22	35	10	" 0·40	Straight	− ·1	" " ..	39	1020	5·52	5·92	
163	2·65. July 20, 1865	6 " 33 "	10	255	35	35	20	" 10·00	1000	+20	Calm and dry ..	15	3345	13·15	3·15	
164	2·65. July 21, 1865	6 " 33 "	8	259	39	40	30	" 10·00	1000	+25	Dry, slight wind	16	3625	13·98	3·98	
165	12·80. Dec. 22, 1865	8 " coupled	10	476	38	92	76	" 4·42	800	0	Calm and dry ..	17	3650	7·65	3·23	
166	12·86. Dec. 22, 1865	8 " "	3	480	38	90	70	" 3·16	1000	− 3	" " ..	25	2810	5·84	2·68	
167	12·86. Dec. 22, 1865	8 " "	7	480	38	90	70	" 5·00	800	− 3	" " ..	13	3630	7·56	2·56	
168	12·80. Dec. 23, 1865	8 " "	9	485	35	97	50	" 4·84	800	0	" " ..	19	3810	7·85	3·01	
16.	12·86. Dec. 23, 1865	8 " "	4	480	35	95	..	" 3·25	1000	− 3	" " ..	19	2600	5·56	2·31	
170	12·86. Dec. 23, 1865	8 " "	8	480	35	95	..	" 4·73	800	− 3	" " ..	15	3640	7·55	2·82	
171	12·72. Jan. 10, 1866	8 " "	5	469	36	97	..	" 5·00	800	+ 1	Damp, slight wind	17	3760	8·00	3·00	
172	12·86. Jan. 10, 1866	8 " "	5	473	40	97	..	" 4·80	800	+ 3	Dry	16	3340	7·01	2·21	
173	12·86. Jan. 10, 1866	8 " "	5	473	40	97	..	" 5·00	800	+ 3	"	16	3760	7·99	2·99	
174	12·72. Jan. 11, 1866	8 " "	7	533	40	97	..	" 4·12	800	+ 3	Wind and rain ..	18	3835	7·18	3·06	
175	12·72. Jan. 11, 1866	8 " "	5	533	40	97	..	" 5·00	800	+ 3	" " ..	12	4690	8·78	3·78	
176	12·80. Jan. 11, 1866	8 " "	5	571	44	95	36	" 4·80	800	+ 7	" " ..	17	4310	7·55	2·75	
177	12·80. Jan. 11, 1866	8 " "	4	571	44	95	36	" 5·00	800	+ 7	" " ..	16	4610	8·05	3·05	
178	12·72. Jan. 12, 1866	8 " "	8	522	41	97	45	" 3·00	1000	+ 2	Dry, slight wind	23	3120	5·95	2·95	
179	12·72. Jan. 12, 1866	8 " "	7	522	41	97	45	" 5·00	800	+ 2	" " ..	13	4510	8·65	3·65	
180	12·72. Jan. 13, 1866	8 " "	7	522	40	93	30	" 4·00	800	+ 1	Calm and dry ..	21	3870	7·42	3·42	
181	12·72. Jan. 13, 1866	8 " "	5	522	40	93	30	" 5·00	800	+ 1	" " ..	16	4490	8·56	3·56	
182	12·91. Jan. 12, 1866	8 " "	2	317	70	..	..	" 5·00	Straight	+ 2	Dry, slight wind	19	2860	9·79	4·79	Trains of empty trucks.
183	12·91. Jan. 13, 1866	8 " "	2	311	71	..	..	" 5·00	"	+ 1	Calm and dry .	24	2720	8·73	3·73	
184	(1) 71. Feb. 4, 1867	6 " 33 tons	3	334	33	21	42	" 9·25	800	..	Fine rain	17	4180	12·51	8·26	Double traction, with frequent slippings, however.
185	(1) 71. Feb. 4, 1867	6 " 33 "	6	334	33	21	42	" 9·25	800	..	"	15	4148	12·42	3·17	
186	(E) 63. Mar. 20, 1867	6 " 33 "	3	156	12	40	66	" 15·00	400	+14	Rain and fog ..	16	2746	17·60	2·60	
187	(E) 63. Mar. 20, 1867	6 " 33 "	3	156	12	40	66	" 16·89	400	+14	" " ..	12	3035	19·42	2·53	
188	(E) 63. Mar. 20, 1867	6 " 33 "	3	156	12	40	66	" 19·80	500	+14	" " ..	10	3460	22·18	2·38	
189	(E) 74. Mar. 22, 1867	8 " coupled	6	233	16	..	100	" 15·50	400	+ 4	Windy, and a little snow	17	4250	18·24	2·74	
	Total distance		1360													

TABLE F.—EXPERIMENTS UPON THE RESISTANCE OF MIXED TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Trucks, &c.	Proportional No. of Trucks.	Proportional No. of Trucks, &c., lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	Temperature.	State of the Atmospher	Speed an hour.	Force of Traction.	Force the ton (absolute).	Force the ton (corrected for gravity).	Observations.
				tons.		per 100.	per 100.	mills.	mètres.	°		kiloms.	kilogs.	kilogs.	kilogs.	
1	100. April 16, 1862	6 wheels, 27 tons	12	207	28	.	..	Incline 0·06	1000	..	Calm and dry ..	34	1067	4·62	5·22	
2	100. April 16, 1862	6 „ 27 „	5	190	25	..	..	Level ..	1000	..	„ „ ..	42	1091	5·75	5·75	
3	100. April 16, 1862	6 „ 27 „	4	190	25	.	..	Incline 3·50	2000	..	„ „ ..	30	1360	7·77	4·27	
4	100. April 25, 1862	6 „ 27 „	14	239	24	0	..	„ 0·11	1000	..	„ „ ..	36	1106	4·53	4·64	
5	100. April 25, 1862	6 „ 27 „	24	227	25	0	..	Level ..	1000	..	„ „ ..	38	1043	4·60	4·60	
6	100. April 25, 1862	6 „ 27 „	4	227	25	0	..	Incline 3·50	2000	..	„ „ ..	30	1410	6·72	3·22	
7	38. Dec. 5, 1862	Mixed, 20 „	38	200	22	0	..	„ 0·15	1000	+12	Slight wind ..	43	1077	5·38	5·53	Double traction.
8	38. Dec. 5, 1862	„ 20 „	15	200	22	0	..	Level ..	1000	+12	„ „ ..	37	934	4·67	4·67	„
9	38. Dec. 5, 1862	„ 20 „	3	162	18	0	..	Incline 3·50	2000	+12	„ „ ..	40	1207	7·44	3·94	
10	100. Nov. 25, 1862	6 wheels, 27 „	16	212	27	37	11	„ 0·09	1000	+ 4	„ „ ..	35	1143	5·36	5·45	
11	100. Nov. 25, 1862	6 „ 27 „	23	197	24	40	15	Level ..	1000	+ 4	„ „ ..	34	1007	5·12	5·12	
12	100. Nov. 25, 1862	6 „ 27 „	3	197	24	40	15	Incline 0·04	Straight	+ 4	„ „ ..	35	1016	5·14	5·54	
13	100. Nov. 25, 1862	6 „ 27 „	5	197	24	40	15	„ 3·50	2000	+ 4	„ „ ..	30	1622	8·25	4·75	
14	38. Dec. 16, 1862	Mixed, 20 „	55	174	18	..	..	„ 0·09	1000	+ 1	Calm, foggy ..	39	755	4·34	4·43	
15	38. Dec. 16, 1862	„ 20 „	5	174	18	..	..	„ 3·50	2000	+ 1	„ „ ..	27	1052	6·75	3·25	
16	80. March 19, 1864	6 wheels, 33 „	14	245	30	33	..	„ 0·16	1000	..	Calm and dry ..	27	1030	4·20	4·36	
17	80. March 19, 1864	6 „ 33 „	21	230	27	40	..	„ 0·16	1000	..	„ „ ..	28	1030	4·48	4·58	
18	80. March 19, 1864	6 „ 33 „	5	230	27	40	..	„ 3·50	2000	..	„ „ ..	25	1710	7·43	3·93	
19	46. Nov. 15, 1864	Mixed, 20 „	23	217	23	75	..	Level ..	1000	+ 9	Contrary wind, rain	51	1300	5·95	5·95	Double traction.
20	46. Nov. 15, 1864	„ 20 „	22	217	23	75	..	Incline 0·10	1000	+ 9	„ „	47	1220	5·62	5·72	„ „
21	46. Nov. 15, 1864	„ 20 „	7	217	23	75	..	Level ..	1000	+ 9	„ „	42	1300	5·98	5·98	„ „
22	46. Nov. 15, 1864	„ 20 „	4	217	23	75	..	Incline 3·50	2000	+ 9	„ „	38	1405	7·24	3·74	„ „
23	46. Nov. 17, 1864	„ 20 „	53	172	19	0	..	„ 0·09	1000	+11	„ „	36	980	5·69	5·78	
24	46. Nov. 17, 1864	„ 20 „	8	172	19	0	..	Level ..	1500	+11	„ „	42	975	5·66	5·66	
25	46. Nov. 17, 1864	„ 20 „	4	172	19	0	..	Incline 3·50	2000	+11	„ „	27	1240	8·26	4·76	
26	46. Nov. 19, 1864	„ 20 „	22	120	14	0	..	„ 0·08	1000	+ 5	Fair	44	660	5·10	5·18	
27	46. Nov. 19, 1864	„ 20 „	22	120	14	0	..	„ 0·10	1000	+ 5	„	52	600	5·00	5·10	
28	46. Nov. 19, 1864	„ 20 „	15	120	14	0	..	„ 0·32	1000	+ 5	„	49	715	5·96	5·64	
29	46. Nov. 19, 1864	„ 20 „	5	120	14	0	..	„ 3·50	2000	+ 5	„	41	706	7·16	3·69	
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TABLE G.—EXPERIMENTS ON THE RESISTANCE OF PASSENGER TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Carriages.	Proportional No. of Carriages lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	State of the Atmosphere.	Temperature.	Speed an hour.	Force of Traction.	Force absolute		Force corrected		Observations.
													a carriage.	a ton.	a carriage.	a ton.	
				tons.		per 100.	mills.	mètres.		°	kiloms.	kilogs.	kilogs.	kilogs.	kilogs.	kilogs.	
1	118. April 8, 1862	Mixed, 20 tons ..	4	48	8	..	Incline 9·00	1000	Slight wind ..	+15	41	850	102	17·03	48	8·03	
2	115. April 8, 1862	„ 20 „ ..	6	48	8	..	„ 9·25	800	„ „ ..	+13	43	940	116	19·41	61	10·16	
3	120. April 9, 1862	„ 20 „ ..	5	47	8	..	„ 9·00	1000	„ „ ..	+15	52	753	104	17·68	51	8·68	
4	119. April 9, 1862	„ 20 „ ..	7	47	8	..	„ 9·25	800	„ „ ..	+15	38	785	98	16·70	44	7·45	
5	120. April 10, 1862	„ 20 „ ..	5	48	8	..	„ 9·00	1000	Fair	+15	49	666	86	14·43	32	5·43	
6	119. April 10, 1862	„ 20 „ ..	7	50	8	..	„ 9·25	800	„	+15	48	803	100	16·12	43	6·87	
7	122. April 12, 1862	„ 20 „ ..	5	49	8	..	„ 9·00	1000	„	+15	48	722	88	14·38	33	5·38	
8	35. April 27, 1862	„ 20 „ ..	6	90	14	..	„ 0·06	1000	„	+14	54	596	44	6·89	44	5·95	
9	35. April 27, 1862	„ 20 „ ..	37	90	14	..	„ 0·10	1000	„	+14	47	596	40	6·34	40	6·24	
10	36. April 30, 1862	„ 20 „ ..	7	91	15	..	Level ..	1000	Slight wind ..	..	58	750	49	8·03	49	8·03	
11	36. April 30, 1862	„ 20 „ ..	25	91	15	..	Incline 0·10	1000	„ „ ..	..	50	703	44	7·16	44	7·26	
12	35. May 1, 1862	„ 20 „ ..	6	101	16	..	Level ..	1200	„ „ ..	..	55	755	43	6·84	43	6·84	
13	35. May 1, 1862	„ 20 „ ..	13	101	16	..	„ ..	1000	„ „ ..	..	48	610	37	5·83	37	5·83	
14	35. May 1, 1862	„ 20 „ ..	7	101	16	..	Incline 0·17	1000	„ „ ..	..	52	646	40	6·40	39	6·23	
15	36. May 6, 1862	„ 20 „ ..	5	101	17	..	„ 0·08	1000	„ „ ..	..	45	620	32	5·29	32	5·37	
16	36. May 6, 1862	„ 20 „ ..	10	101	17	..	Level ..	1000	„ „ ..	..	54	637	35	6·03	35	6·03	
17	36. May 6, 1862	„ 20 „ ..	16	101	17	..	„ ..	1000	„ „ ..	..	49	650	34	5·74	35	5·92	
18	36. May 6, 1862	„ 20 „ ..	10	101	17	..	Incline 0·66	1000	„ „ ..	..	42	603	31	5·95	31	5·29	
19	36. May 6, 1862	„ 20 „ ..	5	101	17	..	„ 2·87	2000	„ „ ..	..	37	740	43	7·29	26	4·42	
20	35. May 7, 1862	„ 20 „ ..	37	106	16	..	„ 0·03	1000	Fair	+17	50	723	44	6·74	44	6·71	Double traction.
21	35. May 7, 1862	„ 20 „ ..	6	106	16	..	„ 0·30	2000	„	+17	41	613	42	6·42	40	6·12	„ „
22	36. Dec. 10, 1862	„ 20 „ ..	11	116	20	..	„ 0·30	1000	Strong wind, rain	+ 7	43	1050	52	9·05	54	9·35	
23	36. Dec. 10, 1862	„ 20 „ ..	11	116	20	..	„ 0·20	1000	„ „ „	+ 7	52	943	47	8·13	48	8·33	
24	36. Dec. 10, 1862	„ 20 „ ..	23	116	20	..	Level ..	1000	„ „ „	+ 7	45	1167	58	10·06	58	10·06	
25	36. Dec. 10, 1862	„ 20 „ ..	17	116	20	..	„ ..	1000	„ „ „	+ 7	49	960	48	8·27	48	8·27	
26	36. Dec. 10, 1862	„ 20 „ ..	6	116	20	..	Incline 3·50	2000	.. ..	+ 7	46	1147	57	9·88	37	6·38	
27	17. April 11, 1862	„ 19 „ ..	8	..	10	..	„ 3·50	1000	.. ..	+15	39	690	69	..	..	..	
28	17. April 11, 1864	„ 19 „ ..	2	..	10	..	„ 5·00	Straight	.. ..	+15	30	682	68	..	..	..	
29	34. April 27, 1864	„ 20 „ ..	12	63	11	..	Level ..	1000	Fair	+13	43	438	39	6·78	39	6·78	
30	34. April 27, 1864	„ 20 „ ..	9	63	11	..	Incline 0·20	1000	„	+13	49	450	41	7·15	42	7·35	
31	34. April 27, 1864	„ 20 „ ..	3	63	11	..	„ 3·50	Straight	„	+13	41	620	56	9·84	36	6·34	
32	35. Nov. 17, 1864	„ 20 „ ..	26	82	14	..	Level ..	1000	Slight wind ..	+ 8	53	750	50	8·59	50	8·59	
33	35. Nov. 17, 1864	„ 20 „ ..	2	82	14	..	Incline 3·50	1000	„ „ ..	+ 8	36	970	65	11·25	45	7·75	
34	35. Nov. 17, 1864	„ 20 „ ..	3	82	14	..	„ 5·00	Straight	„ „ ..	+ 8	35	1110	76	13·10	47	8·10	
35	35. Nov. 19, 1864	„ 20 „ ..	2	98	17	..	„ 3·50	1000	Fair	+ 8	44	1070	55	9·72	35	6·22	Double traction.
36	35. Nov. 19, 1864	„ 20 „ ..	3	98	17	..	„ 5·00	Straight	„	+ 8	34	1240	72	12·65	43	7·65	„ „
37	35. Nov. 19, 1864	„ 20 „ ..	13	98	17	..	„ 0·08	1000	„	+ 8	53	776	42	7·43	42	7·51	„ „
	Carried forward	.. ..	375														

TABLE H.—EXPERIMENTS ON THE RESISTANCE OF PASSENGER TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Carriages.	Proportional No. of Carriages lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	State of the Atmosphere.	Temperature.	Speed an hour.	Force of Traction.	Force absolute a carriage.	Force absolute a ton.	Force corrected a carriage.	Force corrected a ton.	Observations.
	Brought forward		375	tons.		per 100.	mills.	mètres.		°	kiloms.	kilogs.	kilogs.	kilogs.	kilogs.	kilogs.	
38	35. Nov. 19, 1864	Mixed, 20 tons..	6	98	17	..	Incline 0·39	1400	Fair	+ 8	45	895	42	7·42	40	7·03	Double traction.
39	35. Nov. 19, 1864	" 20 " ..	5	98	17	..	Level ..	1000	"	+ 8	59	860	45	7·95	45	7·95	" "
40	31. Nov. 21, 1864	" 20 " ..	5	..	18	..	Incline 1·80	2000	Damp	+ 8	44	920	51	..	..	..	
41	31. Nov. 21, 1864	" 20 " ..	4	..	18	..	Level ..	2000	"	+ 8	49	870	48	..	..	..	
42	31. Nov. 21, 1864	" 20 " ..	3	..	18	..	Incline 3·50	1000	"	+ 8	37	1130	62	..	..	..	
43	31. Nov. 21, 1864	" 20 " ..	15	..	18	..	Level ..	1000	"	+ 8	58	1010	56	..	..	..	Double traction.
44	31. May 4, 1865	" 20 " ..	12	70	12	8	Incline 0·40	1500	Slight wind ..	+27	57	770	56	10·11	53	9·71	
45	31. May 4, 1865	" 19 " ..	6	70	12	8	" 0·40	1000	" " ..	+27	54	673	53	9·61	51	9·21	
46	31. May 4, 1865	" 19 " ..	7	70	12	8	" 0·70	1500	" " ..	+27	47	590	43	8·43	39	7·73	
47	31. May 4, 1865	" 19 " ..	10	70	12	8	" 1·60	Straight	" " ..	+27	52	799	62	11·37	49	9·77	
48	31. May 4, 1865	" 19 " ..	10	70	12	8	" 2·90	1000	" " ..	+27	50	770	62	11·25	46	8·35	
49	31. May 4, 1865	" 19 " ..	9	70	12	8	" 8·00	1000	" " ..	+27	43	963	76	13·80	32	5·80	
50	2·16. July 20, 1865	" 20 " ..	5	78	12	..	" 6·00	700	Fair	+20	37	985	78	11·97	39	5·97	
51	2·16. July 20, 1865	" 20 " ..	6	78	12	..	" 5·33	1000	"	+20	52	958	76	11·64	41	6·31	
52	1·43. July 19, 1865	Free wheels, 9800k	8	64	10	10	" 9·25	800	"	+17	29	835	83	13·00	24	3·75	
53	2·43. July 19, 1865	Mixed, 20 tons..	3	..	13	..	" 5·50	800	"	+17	36	970	74	..	..	..	
54	2·43. July 19, 1865	" 20 " ..	5	..	13	..	" 3·00	800	"	+17	45	860	66	..	..	..	
55	2·16. July 21, 1865	" 20 " ..	11	97	15	7	" 5·63	800	Wind, rain ..	+20	35	1145	76	11·68	39	6·05	
56	2·43. July 21, 1865	" 20 " ..	3	77	13	15	" 5·50	800	Slight wind ..	+20	37	906	67	11·43	35	5·93	
57	2·43. July 21, 1865	" 20 " ..	5	77	13	15	" 5·50	1500	" " ..	+20	44	1000	74	12·57	42	7·07	
58	2·43. July 21, 1865	" 20 " ..	4	77	13	15	" 3·00	800	" " ..	+20	42	766	59	9·92	41	6·92	
59	1·38. July 21, 1865	Free wheels, 9800k	3	40	7	..	" 9·00	2000	Fair	..	44	685	94	16·62	43	7·62	
60	31. Dec. 21, 1865	Mixed, 20 tons..	7	65	12	..	" 0·40	Straight	"	+ 5	55	790	66	12·20	64	11·80	
61	31. Dec. 21, 1865	" 20 " ..	6	65	12	..	" 0·40	1500	"	+ 5	56	810	67	12·45	65	12·05	
62	31. Dec. 21, 1865	" 19 " ..	17	77	15	..	" 0·65	1000	"	+ 5	48	920	60	12·05	62	11·40	
63	31. Dec. 21, 1865	" 19 " ..	3	73	14	..	" 3·90	Straight	"	+ 5	53	940	70	12·90	49	9·00	
64	31. Dec. 21, 1865	" 19 " ..	7	73	14	..	" 8·00	1000	"	+ 5	43	1310	97	18·00	54	10·00	
65	32. Mar. 12, 1866	" 19 " ..	39	99	12	33	" 0·08	1000	Slight wind ..	+ 8	45	770	60	9·10	60	9·18	
66	32. Mar. 12, 1866	" 19 " ..	27	79	12	33	" 0·82	1000	" " ..	+ 8	51	876	68	10·37	63	9·55	
67	33. Mar. 13, 1866	Crampton	45	52	8	..	" 0·03	1000	" " ..	+ 6	77	907	112	17·25	112	17·28	Express.
68	33. Mar. 13, 1866	"	46	52	8	..	" 0·05	1000	" " ..	+ 6	66	915	112	17·34	112	17·29	"
69	32. Mar. 13, 1866	Mixed, 20 tons..	56	88	14	28	" 0·14	1000	" " ..	+ 7	48	760	51	8·86	51	8·22	
70	33. Mar. 14, 1866	Crampton	55	53	8	..	Level ..	1000	Calm, dry ..	+ 2	76	767	96	14·35	96	14·55	Express.
71	33. Mar. 14, 1866	"	40	53	8	..	Incline 0·12	1000	" " ..	+ 2	66	765	94	14·41	94	14·29	"
72	32. Mar. 14, 1866	Mixed, 20 tons..	15	78	12	25	" 0·16	1000	Slight wind ..	+ 6	46	784	63	9·57	63	9·73	
73	32. Mar. 14, 1866	" 20 " ..	27	78	12	25	" 0·14	1000	" " ..	+ 6	52	730	56	8·86	56	8·72	
74	32. Mar. 14, 1866	" 20 " ..	8	78	12	25	" 0·35	2000	" " ..	+ 6	46	664	53	8·45	53	8·10	
	Carried forward		918														

TABLE I.—EXPERIMENTS ON THE RESISTANCE OF PASSENGER TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilometres.	Gross Weight of Train.	No. of Carriages.	Proportional No. of Carriages lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	State of the Atmosphere.	Temperature.	Speed an hour.	Force of Traction.	Force absolute a carriage.	Force absolute a ton.	Force corrected a carriage.	Force corrected a ton.	Observations.
	Brought forward		918	tons.		per 100.	mills.	mètres.		°	kiloms.	kilogs.	kilogs.	kilogs.	kilogs.	kilogs.	
75	33. Mar. 15, 1866	Crampton	64	52	8	..	Incline 0·04	1000	Slight wind ..	+ 2	74	1063	131	20·24	131	20·28	The same carriages as with the train 33 of March 13. Express.
76	33. Mar. 15, 1866	"	36	52	8	..	" 0·13	1000	" " ..	+ 2	67	970	120	18·47	119	18·34	
77	32. Mar. 15, 1866	Mixed, 20 tons	3	72	12	25	" 0·20	Straight	" " ..	+ 8	55	850	70	11·70	71	11·90	
78	32. Mar. 15, 1866	" 20 "	37	72	12	25	" 0·10	1000	" " ..	+ 8	43	875	69	11·50	68	11·40	
79	32. Mar. 15, 1866	" 20 "	6	72	12	25	" 0·77	2000	" " ..	+ 8	52	770	64	10·60	59	9·83	
80	33. Mar. 16, 1866	.. ..	13	53	8	..	" 0·50	1000	" " ..	+ 8	64	750	93	14·10	90	13·60	The same carriages as with the train 33 of March 14. Express.
81	40·35. Apr. 24, 1866	Mixed, 22 "	3	70	12	16	" 5·68	1200	Dry wind ..	+17	44	1120	85	14·68	52	9·00	
82	40·35. Apr. 24, 1866	" 22 "	16	70	12	16	" 1·62	1000	" " ..	+17	45	1007	80	16·83	71	12·21	
83	40·35. Apr. 24, 1866	" 22 "	22	66	11	16	" 1·15	800	" " ..	+17	46	905	83	13·78	76	12·63	
84	40·35. Apr. 24, 1866	" 22 "	7	50	8	25	" 2·66	Straight	Calm, dry ..	+17	45	505	60	10·10	45	7·44	
85	40·35. Apr. 24, 1866	" 22 "	5	50	8	25	" 2·62	2000	" " ..	+17	65	618	74	12·42	58	9·80	
86	40·35. Apr. 24, 1866	" 22 "	15	50	8	25	" 4·34	2000	" " ..	+17	50	610	73	12·21	47	7·87	
87	40·32. Apr. 25, 1866	Free wheels, 11 "	5	55	9	33	" 4·05	1600	" " ..	+15	46	715	73	12·06	49	8·01	
88	40·32. Apr. 25, 1866	" 11 "	3	55	9	33	Level ..	1000	" " ..	+15	60	510	55	9·10	55	9·10	
89	40·32. Apr. 25, 1866	Mixed, 22 "	12	77	12	25	Incline 0·75	800	" " ..	+15	43	566	41	6·40	46	7·15	
90	40·32. Apr. 25, 1866	" 22 "	6	77	12	25	" 5·40	1000	" " ..	+15	35	852	71	11·06	36	5·66	
91	40·32. Apr. 25, 1866	" 22 "	3	77	12	25	" 2·70	Straight	" " ..	+15	44	602	50	7·78	32	5·08	
92	40·32. Apr. 25, 1866	" 22 "	5	70	11	25	" 0·20	1000	" " ..	+15	44	517	45	7·02	46	7·22	
93	40·32. Apr. 25, 1866	" 22 "	3	70	11	25	" 2·28	2000	" " ..	+15	44	610	50	7·87	36	5·59	
94	40·35. Apr. 26, 1866	" 22 "	8	87	14	43	" 4·69	1600	" " ..	..	36	1052	35	12·12	46	7·48	
95	40·35. Apr. 26, 1866	" 22 "	15	87	14	43	" 1·51	1000	" " ..	..	46	926	63	10·20	54	8·69	
96	40·35. Apr. 26, 1866	" 22 "	9	76	12	50	" 0·40	800	" " ..	+26	50	793	56	8·96	54	8·56	
97	40·35. Apr. 26, 1866	" 22 "	6	76	12	50	" 1·49	1000	" " ..	+26	59	776	64	10·20	55	8·71	
98	40·35. Apr. 26, 1866	Free wheels, 11 "	11	56	9	44	" 3·06	Straight	" " ..	+26	47	587	65	10·50	46	7·44	
99	40·35. Apr. 26, 1866	" 11 "	4	56	9	44	" 0·23	"	" " ..	+26	56	627	69	11·20	68	10·97	
100	40·35. Apr. 26, 1866	" 11 "	4	56	9	44	" 6·00	2000	" " ..	+26	39	755	76	12·40	40	6·40	
101	40·35. Apr. 26, 1866	" 11 "	3	56	9	44	" 2·00	2000	" " ..	+20	41	590	57	9·27	45	7·27	
102	40·35. Apr. 26, 1866	" 11 "	14	56	9	44	" 5·14	2000	" " ..	+17	51	690	76	12·32	44	7·18	
103	40·34. Aug. 27, 1866	Mixed, 22 "	6	81	14	20	" 6·00	1500	" " ..	+26	48	995	72	12·51	38	6·51	
104	40·23. Aug. 28, 1866	" 20 "	4	101	17	30	" 2·00	1000	Dry, slight wind	+24	46	900	56	9·43	44	7·43	
105	40·23. Aug. 28, 1866	" 20 "	5	101	17	30	" 5·00	1000	" " "	+24	33	1320	77	12·77	47	7·77	
106	40·23. Aug. 28, 1866	" 20 "	4	101	17	30	" 4·70	1200	" " "	+24	47	1400	71	11·95	43	7·25	
107	40·23. Aug. 28, 1866	" 20 "	3	101	17	30	Level ..	1000	" " "	+24	52	852	39	6·54	39	6·54	
108	41·26. Aug. 28, 1866	" 20 "	2	67	11	..	Incline 6·93	..	" " "	+20	38	907	89	13·50	43	6·57	
109	40·26. Aug. 28, 1866	" 20 "	3	101	17	30	Level ..	1000	" " "	+20	44	885	45	7·52	45	7·52	Same carriages as to train 40/23.
110	40·26. Aug. 28, 1866	" 20 "	2	101	17	30	Incline 2·42	2000	" " "	+20	44	1122	53	8·85	99	6·43	
111	35. June 4, 1866	" 20 "	6	105	17	..	" 0·20	2000	Calm, rain ..	+19	61	670	51	8·29	50	8·09	
112	35. June 4, 1866	" 20 "	3	105	17	..	" 3·50	1000	" " ..	+19	44	1270	71	11·47	49	7·97	
	Carried forward		1294														

TABLE J.—EXPERIMENTS ON THE RESISTANCE OF PASSENGER TRAINS.

No.	Designation of Train.	Type of Engine, and Adhesive Weight.	Distance experimented over in kilomètres.	Gross Weight of Train.	No. of Carriages.	Proportional No. of Carriages lubricated with Oil.	Nature of the Line.	Minimum Radius of Curves.	State of the Atmosphere.	Temperature.	Speed an hour.	Force of Traction.	Force absolute a carriage.	Force absolute a ton.	Force corrected a carriage.	Force corrected a ton.	Observations.
	Brought forward		1294	tons.		per 100.	mills.	mètres.		°	kiloms.	kilogs.	kilogs.	kilogs.	kilogs.	kilogs.	
113	35. June 4, 1866	Mixed, 20 tons ..	8	105	17	..	Incline 5·00	800	Calm, rain ..	+19	38	1340	74	12·00	43	7·10	
114	35. June 4, 1866	„ 20 „ ..	21	105	17	..	„ 0·17	1000	„ „ ..	+19	53	852	43	6·91	42	6·74	
115	35. June 4, 1866	„ 20 „ ..	6	105	17	..	„ 0·22	1000	„ „ ..	+19	57	890	47	7·60	48	7·82	
116	35. June 4, 1866	„ 20 „ ..	5	105	17	..	„ 0·24	Straight	„ „ ..	+19	63	973	52	8·40	50	8·16	
117	1·35. June 4, 1866	Free wheels, 9800k	4	45	8	..	„ 9·25	800	Calm, damp ..	+20	87	817	101	18·00	49	8·75	
118	2·13. June 5, 1866	Mixed, 20 tons ..	9	49	9	11	„ 5·50	800	Calm, dry ..	+20	31	585	64	11·83	34	6·33	
119	2·13. June 5, 1866	„ 20 „ ..	8	49	9	11	„ 10·00	1000	„ „ ..	+20	29	750	86	15·42	30	5·42	
120	2·16. June 5, 1866	„ 20 „ ..	2	61	10	10	„ 3·00	1000	„ „ ..	+23	46	760	61	10·11	43	7·11	
121	2·16. June 5, 1866	„ 20 „ ..	5	61	10	10	„ 2·00	1000	„ „ ..	+23	61	822	72	11·80	60	9·80	
122	2·16. June 5, 1866	„ 20 „ ..	4	61	10	10	„ 3·40	1000	„ „ ..	+23	56	710	71	11·60	50	8·20	
123	2·16. June 5, 1866	„ 20 „ ..	4	61	10	10	„ 5·80	700	„ „ ..	+23	46	873	80	13·23	45	7·43	
124	2·16. June 5, 1866	„ 20 „ ..	6	61	10	10	„ 5·20	1000	„ „ ..	+23	57	867	83	13·64	51	8·44	
125	2·43. June 6, 1866	„ 20 „ ..	11	68	11	9	„ 5·50	800	„ „ ..	+18	33	949	74	13·50	50	8·06	
126	2·43. June 6, 1866	„ 20 „ ..	8	68	11	9	„ 10·00	1000	„ „ ..	+18	37	1087	98	15·77	36	5·77	
127	2·16. June 6, 1866	„ 20 „ ..	14	58	10	30	„ 2·63	1000	„ „ ..	+23	46	623	59	10·19	44	7·56	
128	2·16. June 6, 1866	„ 20 „ ..	13	58	10	30	„ 5·63	700	„ „ ..	+23	39	743	71	12·32	39	6·69	
129	2·43. June 7, 1866	„ 20 „ ..	10	64	11	27	„ 5·50	800	„ „ ..	+20	41	812	67	11·60	36	6·18	
130	2·43. June 7, 1866	„ 20 „ ..	5	64	11	27	„ 3·00	800	„ „ ..	+20	46	724	60	10·40	43	7·40	
131	2·43. June 7, 1866	„ 20 „ ..	10	64	11	27	„ 10·00	1000	„ „ ..	+20	37	1067	94	6·61	36	6·19	
132	2·16. June 7, 1866	„ 20 „ ..	4	62	10	30	„ 2·00	1000	„ „ ..	+27	51	636	63	8·59	41	6·59	
133	2·16. June 7, 1866	„ 20 „ ..	16	62	10	30	„ 5·03	700	„ „ ..	+27	45	697	66	10·65	35	5·62	
134	1·16. June 7, 1866	Free wheels, 9800k	6	53	10	10	„ 9·00	1000	„ „ ..	+25	42	850	85	16·10	38	7·10	
135	44. June 8, 1866	Mixed, 20 tons ..	10	107	17	17	„ 0·18	1000	„ „ ..	+25	46	627	37	5·85	38	6·03	
136	44. June 8, 1866	„ 20 „ ..	5	107	17	17	„ 0·40	1400	„ „ ..	+25	44	547	32	5·08	34	5·48	
137	44. June 8, 1866	„ 20 „ ..	28	107	17	17	Level ..	1000	„ „ ..	+25	46	588	36	5·67	36	5·67	
138	44. June 8, 1866	„ 20 „ ..	16	107	17	17	„ ..	1000	„ „ ..	+25	45	672	39	6·27	39	6·27	
139	44. June 8, 1866	„ 20 „ ..	6	107	17	17	Incline 2·80	2000	„ „ ..	+25	46	830	53	8·46	35	5·66	
140	9. Aug. 3, 1866	„ 20 „ ..	11	77	13	45	Level ..	1000	Dry, slight wind	+20	45	645	46	7·73	46	7·73	
141	9. Aug. 3, 1866	„ 20 „ ..	2	77	13	45	Incline 3·50	1000	„ „ „	+20	30	732	49	8·13	28	4·63	
142	9. Aug. 3, 1866	„ 20 „ ..	2	77	13	45	„ 5·00	800	„ „ „	+20	24	635	53	8·94	21	3·94	
143	9. Aug. 3, 1866	„ 20 „ ..	3	77	13	45	Level ..	1500	„ „ „	+20	40	600	46	7·78	46	7·78	
144	9. Aug. 3, 1866	„ 20 „ ..	14	77	13	45	Incline 0·14	1000	„ „ „	+20	47	700	52	8·76	53	8·90	
145	20. Aug. 3, 1866	„ 20 „ ..	16	73	12	42	Level ..	1000	„ „ „	+24	45	796	61	10·19	61	10·19	
146	20. Aug. 3, 1866	„ 20 „ ..	5	73	12	42	„ ..	1000	„ „ „	+24	51	785	62	10·42	62	10·42	
147	20. Aug. 3, 1866	„ 20 „ ..	4	73	12	42	Incline 0·20	1000	„ „ „	+24	34	784	64	10·75	65	10·95	
148	20. Aug. 3, 1866	„ 20 „ ..	4	73	12	42	„ 0·33	Straight	„ „ „	+34	51	780	62	10·37	64	10·70	
149	1·36. Feb. 4, 1867	Free wheels, 9800k	3	30	5	20	„ 9·00	1000	Wind and rain	..	40	620	124	20·39	68	11·39	Through a tunnel.
150	1·36. Feb. 4, 1867	„ „	4	30	5	20	„ 5·00	Straight	Wind	..	45	544	91	16·23	67	11·23	
	Total distance		1360														

Note K.—Composition of the Grease in use on the Eastern Railway (*of France*).—The experiments to which we have referred when considering friction in a grease-box, were made with the grease and oil now used on the Eastern Railway. The grease is composed as follows;—

Winter grease	White tallow	0·123
	Grey tallow	0·123
	Palm oil	0·123
	Old grease	0·123
	Pure water	0·388
	Lye	0·120
		1·000
Summer grease	White tallow	0·22
	Grey tallow	0·22
	Pure water	0·41
	Lye	0·15
		1·00

For oil-boxes, unpurified colza oil is used.

It will be seen from the above, that the lubricating substance employed was only of ordinary quality. By using better grease, coefficients may be obtained approaching nearer and nearer to those found for oil.

EARTHWORK. Fr., *Terrassement; Ger., Erdbau; Erdschüttung;* Ital., *Lavori di terra;* Span., *Movimiento de tierras.*

See Embankment. Fortification. Railway Engineering.

ECCENTRIC. Fr., *Excentrique;* Ger., *Excentrik;* Ital., *Eccentrico;* Span *Escéntrico.*

See Cam. Details of Engines, p. 1196. Mechanical Movements.

EFFLUX CHAMBER. Fr., *Chambre d'écoulement; Écouloir;* Ger., *Auslauf; Ausmündung;* Span., *Cámarama de salida.*

The *efflux* and *influx* chambers (Brooklyn Water-works, U.S.), at Ridgewood, possess some points of novelty that deserve the attention of engineers.

The influent chamber is placed at the south end of the division embankment, and the effluent chamber at the north end of the same embankment. Each chamber is arranged to communicate with both compartments of the reservoir, or with either compartment at will. The distance between the two chambers is 1215 ft. The water, therefore, received into either compartment of the reservoir, from the influent chamber, has more than this distance to travel before reaching the chamber whence it is delivered to the city, and during its imperceptible progress, as regards velocity, between these two points, it has ample time to deposit any sediment with which it may have been charged. But as it very rarely happens that the water in the conduit or pump-well is affected in this way, it usually reaches the reservoir clear as spring water. For this character of water, two divisions in the reservoir would not have been necessary, as providing from one to the other for the intermittent retention necessary to subsidence, one compartment would have equally satisfied the necessities of the case as to that point; but the two are necessary as a means of cleaning and repairing the reservoir without drawing off more than half of its reserve of water.

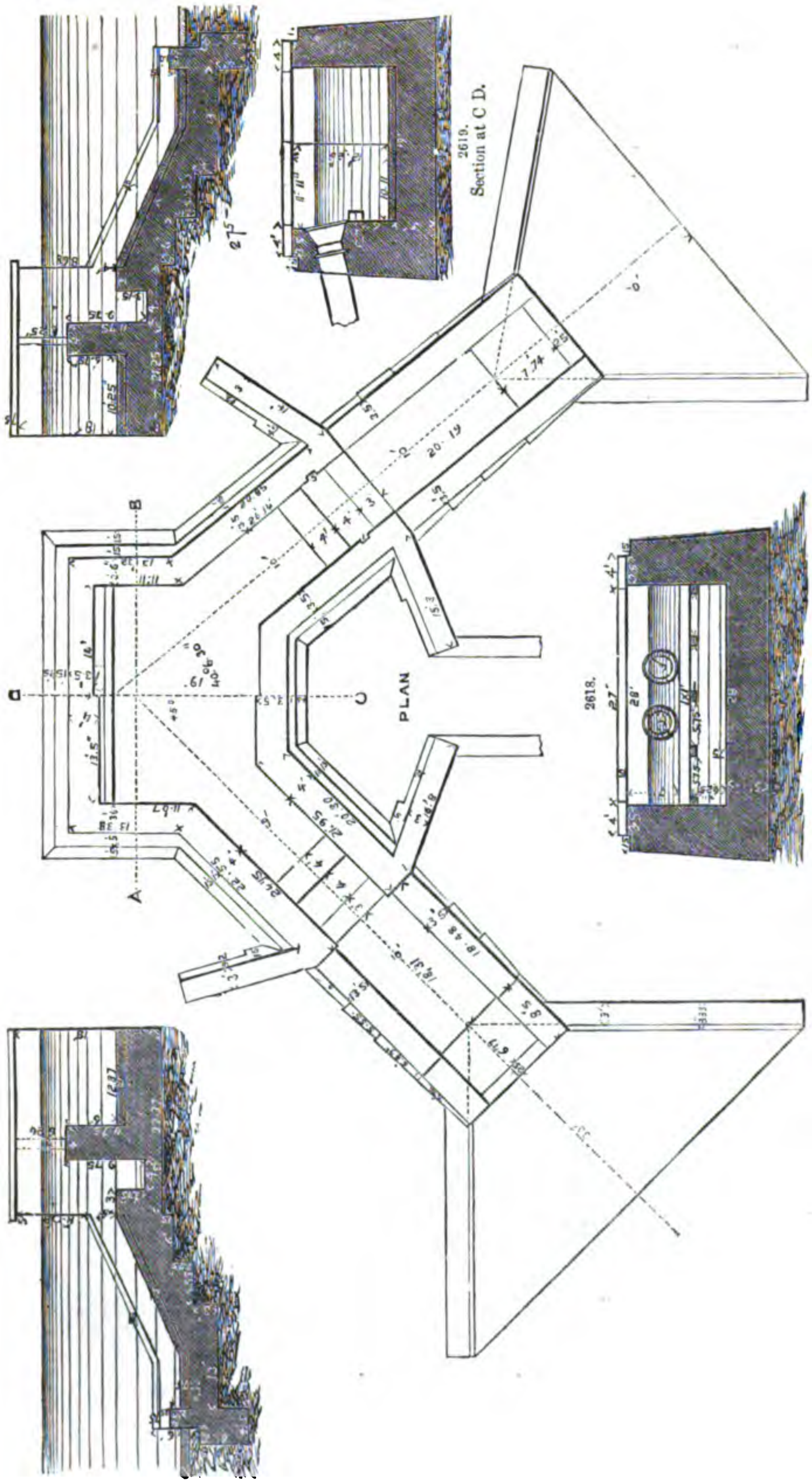
The influent chamber is in length 28 ft., width 19 ft.; the bottom is situated 6 ft. below high water of the reservoir, and 4½ ft. below the centre of the mouth of the delivering pipes. From this pool, or chamber of water, an open passage communicates with the western division of the reservoir, and another with the eastern division. Either of these passages can be shut off by flash-boards, and the whole delivery, in that case, thrown into the opposite division. The water, flowing through these passages, falls, when the reservoir is low, into a shallow well of water, placed there to protect the paving of the slope from the wear of the falling water; thence it reaches the reservoir over a brick paving set on edge, laid in mortar, and resting on the heavy stonework of the foundations. A portion of the bottom of the reservoir is paved here, to defend the bottom when the water first touches it. This paving is of stone, laid in hydraulic mortar. These last details are not seen when the reservoir is full.

The masonry of the work consists of granite, carried up in courses, the face-stones being cut in bed and build, and dressed to the lines of the work. The whole is laid in hydraulic mortar, composed as already described. Figs. 2615 to 2619 give the details of the foundations and other particulars.

The influent chamber is large enough to receive the terminal pipes of four force-mains, being the number necessary to deliver the waters of four engines, each of 10,000,000 gallons daily capacity, covering, therefore, the 40,000,000 of supply contemplated in the design of these works, half of which supply is provided for.

The chamber shows but two delivery-pipes now, being the mouths of the force-mains in current use. These terminal pipes are carefully built into the masonry, the back of which, in contact with the earthen embankments, is carefully puddled all round, this puddle being connected with the puddle of the reservoir. A separate piece of masonry, situated at the foot of the exterior slope of the bank, holds and envelops the mains there also, and secures the pipes from any longitudinal motion within the reservoir grounds, and from the leakage which such motion might entail. An inspection of the sharp inclination upon which the force-main pipes are laid, below the reservoir, will show the risk of some such effect being produced there.

The *effluent chamber*, Figs. 2620 to 2624, is arranged so as to connect the city supply-mains with the water of either division of the reservoir, or with both, at convenience. Kirkwood's object was, in both chambers, to simplify as much as possible, the connection of the mains with the reservoir



2615.

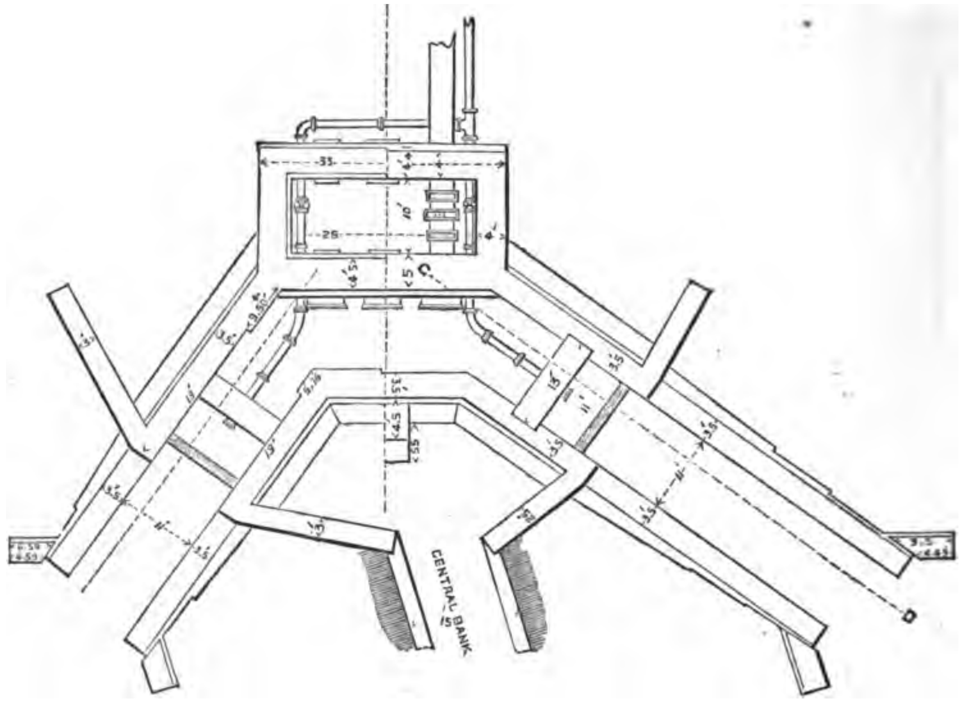
2616.
East Wing Wall of East Inlet.

2617.
West Wing Wall of East Inlet.

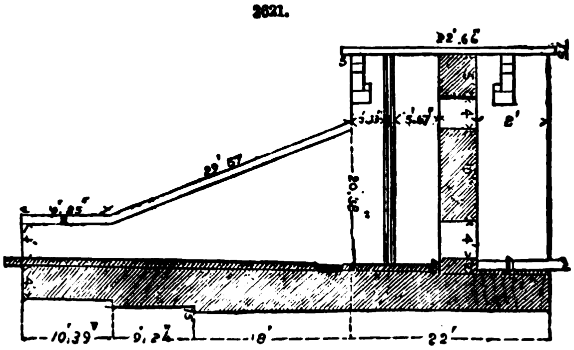
2618.
Section at A B.

2619.
Section at C D.

2620

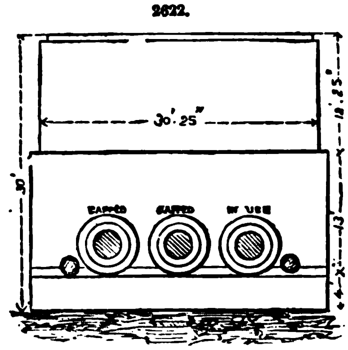


2621.



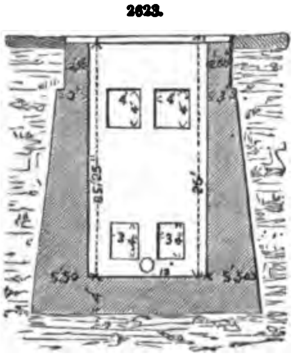
Section at D C.

2622.



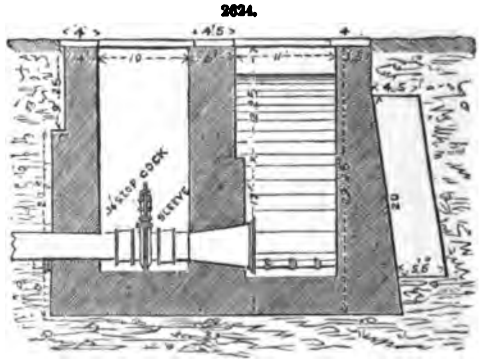
Elevation of Front Wall of Chamber.

2623.



Section of Granite Pier.

2624.



Section through Chambers.

compartments, and at the same time to make their pipes easily accessible for repairs, complicating as little as possible, under such circumstances, the reservoir works.

The water-space of the effluent chamber is connected, by passages 11 ft. wide, with the two divisions of the reservoir. A heavy granite wall is built across each passage, rising to the same level as the top of the reservoir banks. In each wall there are four openings, the two lower openings being 3 × 3 each, and the two upper openings 3 × 4 each. Iron sluices running in iron slides, faced with composition metal, cover and control these openings. From these sluices, iron rods of 2 in. diameter rise to the top of the work, where they terminate in screws and gearing for the movement of these sluices. The faces of these iron sluices are parallel;—it is evident now that they would have been tighter, had the sluices been wedge-shaped, like the sluice-gates of ordinary stop-cocks. The possibility of their getting fixed in that case, induced the engineers to have them made as they are.

In front of the sluices, towards the reservoir, in each passage, copper-wire screens are placed, 22 ft. in height, to prevent fish, leaves, &c., from passing into the effluent chamber, and so into the supply-pipes. As a further precaution, a screen of similar material defends the pipe-mouth.

Immediately behind the effluent chamber proper, but connected with it, there is a dry chamber, open to the surface, except as it is now covered by a movable iron roofing. The supply-mains pass through this dry chamber, and it is here that the stop-cocks of these mains and the stop-cocks of the waste-pipes are placed. Into the granite wall, 6 ft. thick, separating this chamber from the water chamber, the three mouth-pipes of the three pipe-mains, each of 36 in. diameter, are built in place. There is but one of these mains in use now, and but one large stop-cock in the chamber at present; the mouths of the other pipe-mains are for the present closed in front. Into the opposite wall of the stop-cock chamber, pieces of the same sized mains are built, in order that when a second or third main is required to be laid, it may not be necessary to break into any of the masonry. In the same chamber the stop-cocks of the waste-pipes are found. These waste-pipes are of 12 in. diameter, and communicate with each division of the reservoir, their stop-cocks being closed, except when, in the course of drawing the water off either division, the bottom is desired to be drained off thoroughly. This drainage water is carried by a 12-in. pipe to a pond hole on the opposite side of the turnpike road. The mouths of these drain-pipes are outside of the copper screens, as will be seen in Figs. 2620 to 2624.

The bottom of this chamber as well as of the effluent chamber proper, is paved with hard-burnt brick, set on edge, and laid in cement mortar. The masonry is of blue stone, finished with coursed granite, except the heavy foundations, which are of rubble-work. The whole work is laid in hydraulic cement mortar. The earthwork of the division embankments, where it connects with the masonry, was carefully rammed, and the puddle wall of the embankment was widened there, so as to cover the whole space between the buttresses. The puddle was enlarged in the same manner behind the walls of the influent chamber.

The apparatus for moving the sluices is protected by a small house built over each passage.

The paving of the reservoir slopes, where they meet the top lines of the banks, is finished by a dwarf wall, and blue stone coping, upon which there is placed a low iron fence.

ELECTRIC TELEGRAPH. Fr., *Télégraphe électrique*; Ger., *Electrische Telegraph*; Ital., *Telegrafo elettrico*; Span., *Telégrafo eléctrico.*

An *Electric Telegraph*, or *Electro-Magnetic Telegraph*, is a telegraph in which the operator at one station causes words or signs to be recorded or exhibited at another by means of a current of electricity, generated by a *battery*, and transmitted over an intervening wire. See Telegraphy.

ELECTRO-MAGNET. Fr., *Aimant-électrique*; Ger., *Electrischer Magnet*; Ital., *Calamita temporaria*; Span., *Iman eléctrico.*

See Boring and Blasting, p. 572.

ELECTRO-METALLURGY. Fr., *Électro-métallurgie*; Ger., *Electrometallurgie*; Ital., *Elettro-metallurgia*; Span., *Electrometalurgia.*

Electro-metallurgy is the art of depositing metals from solutions of their salts upon metallic surfaces by the action of voltaic electricity. The most extensively known of the many specific processes included under this generic name is that of electrotype, the use of which is;—

1st. To deposit upon a baser metal a thin, continuous, and adherent layer of a more precious and less oxidable metal; or,

2nd. To obtain a continuous layer of metal, but not adherent, and of sufficient thickness to allow of its being separated from the subjacent object of which it gives an exact copy. This is the real use of the electrotype, properly so called.

By those processes of the hydroplastic art which do not require the aid of electricity, only thin layers can be obtained, and the results are of the nature of those comprised in the first case mentioned above. These deposits are called *direct deposits*, or deposits by simple immersion; the most common being those of gold and silver. We cannot affirm that direct deposits are effected without the aid of electricity, for the presence of two different metals in the fluid produces a real galvanic battery. But we shall retain this name for those deposits which are effected without the assistance of a source of electricity external to the bath itself. There are, moreover, deposits called *deposits by double affinity*, which are produced by the contact of two metals in proper solutions. The most remarkable examples of these deposits are Roseleur's process of tinning and the process of coppering known as Weill's.

Cleaning.—Before we consider these different deposits, we must say a few words concerning the preparation of the metals by cleaning. This operation, or rather, this series of operations, is desired to remove from the surface of the objects every trace of foreign substances, previously to their being immersed in the bath. This preparation is of the highest importance, for if it is impossible to obtain a good deposit in a bad bath, it is no more possible to obtain in an excellent bath a good deposit upon a piece which has been imperfectly cleaned.

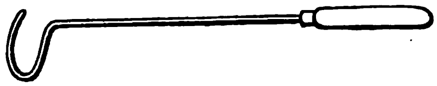
The mode of cleaning is not the same for all metals, and it may be *mechanical* or *chemical*. The

chemical process gives much more perfect results than the mechanical, but, unfortunately, it can be applied only to copper and its alloys. For all the other metals the chemical action may be employed to begin the cleaning, but in nearly all cases it must be finished mechanically.

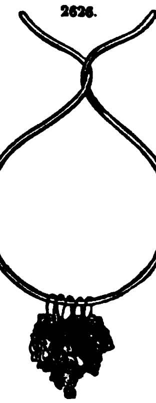
Cleaning Copper and its Alloys.—The first thing to be done is to remove all greasy substances which accumulate on the surface of the metal, either during the processes of manufacture or from frequent contact with the hands. This result is obtained by two methods. The first consists in subjecting the metal to a temperature producing red heat; this method cannot be applied to objects which have soldered joints, nor to those whose fragility would render them liable to injury, nor again to those which are required to retain their rigidity and sonorousness. In these cases recourse is had to the second method, which consists in placing the objects for several minutes in a boiling solution of potash and soda.

When removed from this bath they are well rinsed and then placed in a mixture of from 5 to 20 parts of sulphuric acid 66° and 100 parts of water, where they are allowed to remain until the black layer of bioxide of copper is transformed into a reddish layer of protoxide of copper. They are afterwards attached to copper hooks of various shapes, according to the weight and nature of the articles, Figs. 2625 to 2627, or placed in a kind of strainer made of grit stone, Figs. 2628 to 2630,

2625.



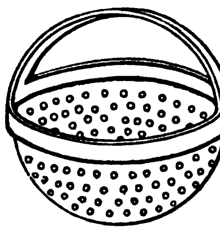
2626.



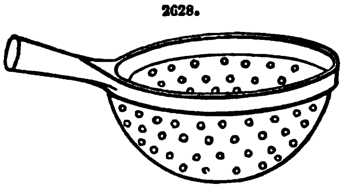
2627.

2630.

2629.



2628.



to enable the operator to shake them easily when passing them through the various acids, and which are;—

1st. *Weak aquafortis.* This is nitric acid (aquafortis) nearly exhausted by previous use. The objects are allowed to remain in it for several seconds. The advantages of employing weak aquafortis are, 1, a saving of new acids; and 2, a less violent action upon those light parts, certain portions of which are covered with oxide while the rest is metallic.

2nd. *Strong aquafortis.* This is composed of

Azotic acid 36°	10 litres.
Sea salt	100 grammes.
Calcined soot	100 „

The articles are placed in this for some seconds, then they are exposed to the air until the surface is covered with a kind of green froth; they are then plunged again into the strong aquafortis, after which they are well rinsed.

3rd. *Compounds for brightening the metal.* When taken out of the aquafortis, the articles have a bright and metallic appearance which seems to indicate a state of perfect cleanliness. It is not so, however, and if we attempt to gild by immersion an article just taken from the aquafortis, the operation will probably result in failure. The case will be otherwise, however, if we pass the article through a mixture of

Nitric acid 36°	10 litres.
Sulphuric acid 66°	10 „
Sea salt	100 grammes.

On being taken from this bath the article will have a bright and clean appearance, and the operation of cleansing will have been thoroughly performed.

If, instead of a bright surface, we require a dull one, the formula of the component acids will be modified as follows;—

Azotic acid 36°	20 litres.
Sulphuric acid 66°	10 „
Sea salt	100 grammes.
Sulphate of zinc	200 „

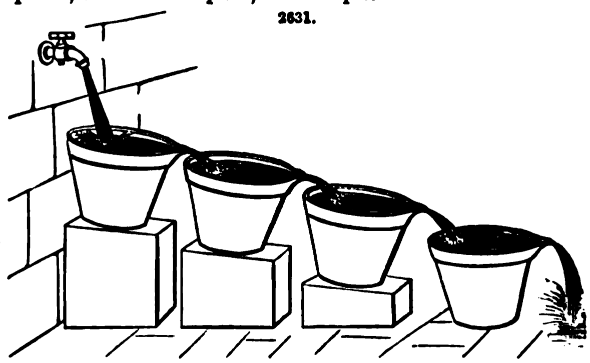
The articles must be left in this bath from one to ten minutes, according to the degree of dulness required, and this dulness, which will in all cases be too deep, must be lightened by passing the articles rapidly through the brightening compounds.

Another operation is often performed for the purpose of facilitating the adherence of the metal, and it consists in plunging rapidly the articles, after they have undergone the cleansing process, into the following solution;—

Water	10 litres.
Azotate of mercury	5 grammes.
Sulphuric acid	10 „

The above solution is suitable for gold. But the quantity of salt of mercury must be increased when thick deposits of silver are required, such as table-plate, for example.

2631.



The series of operations for the complete cleansing of copper and its alloys are, thus, the following;—

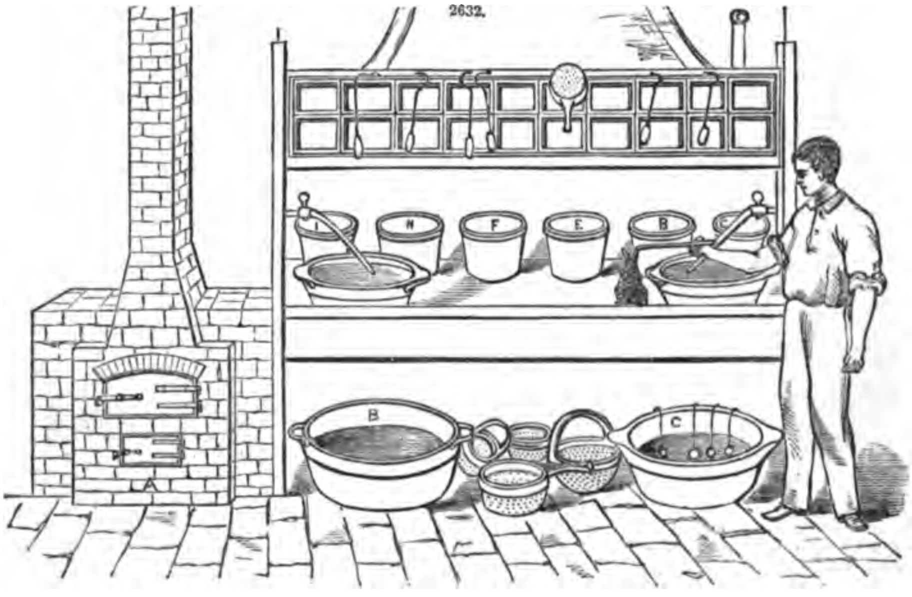
The removal of grease.
Bath of sulphuric acid.
Bath of weak aquafortis.
Bath of strong aquafortis.
Baths of acid compounds.
Bath of nitrate of mercury.

Between each of these operations a thorough rinsing is necessary.

Thus a series of pans, arranged as shown in Fig. 2631, are required, the rinsing beginning in the lowest and ending in the highest, which contains water free from acid.

Fig. 2632 represents;—A, furnaces for heating the articles; B, pan for the sulphuric acid bath; C, pot of weak aquafortis; D, pot of strong aquafortis; E, pot of compounds for dulling the metal; F, pot of compounds for brightening the metal; G, azotate of bioxide of mercury.

2632.

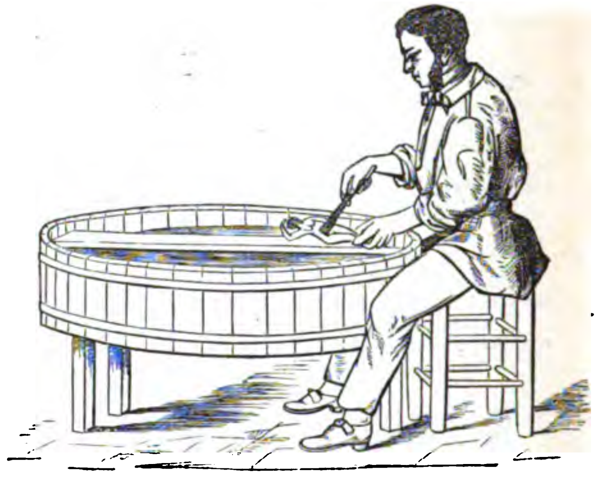


Cleansing by Mechanical Means.—The cleansing by this means is effected by the aid of revolving of hand brushes. Figs. 2636, 2637, represent hand-brushes made of fine brass wire. For very

delicate objects spun glass is used. The brush represented by Fig. 2638 is intended for large bronze articles. Figs. 2633 to 2635 show the manner in which these brushes are employed; they are also used to brighten dull deposits, previously to the operation of burnishing.

2633.

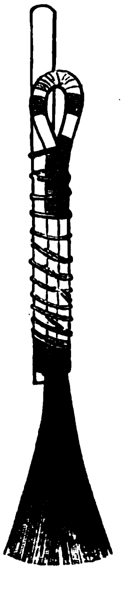
2634.



2635.

2636.

2637



2638.

To Clean Silver, Zinc, Iron, &c.—We have already said that the cleansing of metals other than copper and its alloys is in nearly all cases effected by mechanical means. The following are the processes for the common metals;—

Silver is first heated either by placing it directly in the fire or by enclosing it first in iron boxes, and then plunged in sulphuric acid diluted with water. The cleansing is afterwards completed by brushing. Azotic instead of sulphuric acid is sometimes employed, but if the acid is not free from chlorine, chloride of silver will be formed on the surface of the object.

Zinc is cleaned without much difficulty when it is not joined with tin or lead. Unfortunately in practice zinc articles are nearly always soldered. In any case, however, the following process, which has hitherto been seldom employed, gives satisfactory results.

The grease being removed by a boiling solution of potash, the articles are passed rapidly through a liquid composed of

Sulphuric acid 66°	10 litres.
Azotic acid 36°	10 „
Sea salt	100 grammes.

This bath should be used exclusively for zinc, and should not contain salts of copper, which would be reduced by the zinc, thereby causing a blackened surface. The articles must be well rinsed and the cleaning completed by means of brushing.

Iron is cleansed by being immersed for several hours in a very weak solution of sulphuric acid in water—a hundredth of acid is enough—and then brushed with iron-wire or coarse short hair-brushes. Hydrochloric acid is sometimes used, but sulphuric acid is to be preferred, because it does not evaporate like hydrochloric acid. When the metal has been cleaned, it is kept in water slightly alkalized, if it is not required to place it at once in the bath.

Steel is cleaned in the same way as iron, but it requires to be left for a shorter time in the acidulated water.

Aluminium may be well cleansed in the following manner;—

1. A short immersion in caustic water;
2. An immersion of several minutes in pure nitric acid, which does not act upon the aluminium, but which destroys impurities on its surface;
3. A rapid passage through very weak fluorhydric acid;
4. A passage through liquid phosphoric acid.

If the aluminium is pure, the object, when taken out of the last bath, has a white and brilliant appearance.

Lead and tin cannot be cleaned by means of acids; recourse must, in these cases, be had to the brush and some fine powder, such as pounce.

Metallic Deposits obtained by Simple Immersion.—Metallic deposits by simple immersion may be considered as particular cases of the general law of the precipitation of metals by other metals more oxidable. The conditions to be fulfilled in the case we are considering are the following;—the precipitated metal should form on the surface of the precipitating metal a uniform, continuous, and adherent layer, possessing all the qualities peculiar to it, such as brilliancy, colour, hardness, unchangeableness, when exposed to the influence of atmospheric agents, &c.

It is seldom that the precipitation of metals can be effected with all these conditions without the aid of electricity. The general principle of direct deposits is this;—

If a metal be placed in a solution of another metal less oxidable, the more oxidable will substitute itself for the other metal in the solution, whilst the latter will be precipitated in a metallic state in equivalent atomic proportions.

Most commonly the metal is precipitated in a pulverulent state and has no adhesion with the subjacent metal. Sometimes, on the contrary, as in the cases of gilding and silvering by immersion, extremely adhesive deposits are obtained.

It seems reasonable to suppose that in all cases the effects produced are not due merely to chemical affinity, but that they result in part from the electric current caused by the contact of two metals in a liquid which exerts a chemical action upon them.

It follows from what we have said above that with direct deposits only very thin layers can be obtained, since the action must evidently cease when the whole surface of the oxidable metal is covered, there being then in reality only one metal in contact with the liquid. We shall have occasion later to notice an exception to this general rule in the case of silvering by the method of dipping with bisulphate of soda, but this does not weaken the theory of direct deposits.

The following is, according to M. Dumas, the Table of metallic salts reducible by other metals, and of those the solutions of which are not reducible by the metals;—

Salts, the Solutions of which are Irreducible by the Metals	Salts, the Solutions of which are Reducible by certain Metals		
Manganese.	Tin.		
Zinc.	Antimony.		
Iron.	Arsenic.		
Chromium.	Bismuth.		
Cobalt.	Lead.		Reduced by iron, zinc, and perhaps manganese.
Cerium.	Copper.		
Uranite.	Tellurium.		
Titanium.	Nitrate of Mercury	Reduced by iron, zinc, and all the above.	
Nickel.			
	Silver ..	Reduced by zinc, manganese, cobalt, and all those which precede silver.	
	Palladium		
	Rhodium		
	Platina ..		
	Gold ..		
	Ormium		
	Sodium ..		

Berzélius gives the following series in which each metal is reduced from its solution by those which follow it;—

Gold,—silver,—mercury,—bismuth,—copper,—tin,—zinc.

Between the state of the precipitate and the decomposing force there exists a certain relation. In general, a too energetic action gives pulverulent deposit, whilst a tardy action gives either an adherent metallic layer, or flakes, or, again, crystals. Thus, solutions had to be sought which would give up their metal in contact with another metal, but with sufficient slowness to avoid a pulverulent deposit.

Gilding by the Method of Dipping.—It was not till a great number of experiments were made that the conditions necessary for a good deposit were discovered and fulfilled. We shall describe only the most important of these; but we shall give more in detail the methods actually in use.

Gilding by immersion is applicable only to silver, to copper, and its alloys, or to metals previously coppered. Baumé obtained the first success by means of a bath formed simply of a solution of chloride of gold, as neuter as possible. By this process small pieces of clock-works may be gilded with some degree of success; but the bath soon became acid, which destroyed its efficacy. This result, long known by experience, is confirmed by theory. The gold exists in this bath in the state of perchloride Au^2Cl^3; therefore, there must be *three* equivalents of copper entering into dissolution for *two* equivalents of gold precipitated, in order that no chlorine may be set free. An attempt was next made to dissolve the chloride of gold in sulphuric ether, with results slightly more satisfactory. Macquer, in his Dictionnaire de Chimie, proposed to employ an alkaline solution instead of the acid one. This was the first step in a practical direction. Proust, Pelletier, and Duportal, were perfectly successful in an attempt to gild copper with a solution of chloride of gold in carbonate of potash. This method was improved by Elkington, who patented his invention in 1836.

Elkington's method, which was the only one employed for some years, consists of the following processes;—

In an iron vessel, gilded on the inside by boiling an old bath in it, this mixture was placed and made to boil,

Bicarbonate of potash	9 kilogrammes.
Chloride of gold	240 grammes.
Water	16 litres.

The boiling was continued for at least two hours, the water being renewed as it evaporated. At the expiration of this time, a portion of the gold has been precipitated under the form of a purplish black powder. The whole is then left to cool and decanted. A second boiling is requisite to render the bath fit for use; it is then of greenish colour.

When baths for gilding by simple immersion in an alkaline solution were first invented, the reaction which takes place was explained in various ways. It was even asserted that the perchloride of gold was transformed into protochloride under the influence of certain organic matters, such as saw-dust, capable of reducing gold. It was easy to refute this opinion, for articles which have not been dried may be gilded as well as those which have been dried by saw-dust.

M. Barral has propounded a theory which seems to explain facts in a rational manner. He shows that in a bicarbonate bath two equivalents of copper are dissolved while two equivalents of gold are deposited. Further, he has proved that in a bath absolutely exhausted, we shall find chloride of potassium and chlorate of potash instead of bicarbonate. M. Barral thinks, therefore, that for two equivalents of gold precipitated, there are three equivalents of chlorine set free. Two of these three equivalents form chloride of copper at the expense of the object immersed, and one equivalent seizes upon the potash. To represent this reaction, we may, therefore, write the formula

$$3\,Au^2Cl^3 + 6\,KO + 6\,Cu = 3\,Cu^2Cl + 5\,ClK + ClO^6K + 3\,Au^2.$$

Or if we admit the formation of bichloride of copper, we shall have

$$6\,Au^2Cl^3 + 12\,Cu + 6\,KO = 12\,CuCl + 5\,ClK + ClO^6KO + 6\,Au^2.$$

The latter reaction is the more probable, on account of the greenish blue tint which the liquid assumes.

The whole of the gold contained in this bath cannot be utilized. We must stop when a third or at most a half of the gold in solution has been deposited. This defect added to that of giving good results only when the bath is very much concentrated, has led to the nearly general rejection of this kind of bath.

Roseleur's Process.—This process is now employed almost to the exclusion of all others. The inventor, M. Alfred Roseleur, to whose labours most of the progress hitherto made in this art is due, has furnished us with some practical details, which have been tested by our own experience.

The best bath is composed of

Distilled water	10 litres.
Pyrophosphate of soda	800 grammes.
Cyanhydric acid	8 „
Chloride of gold	20 „

This quantity of chloride of gold represents 10 grammes of gold treated by the aqua regalis.

To prepare this bath, heat 9 litres of distilled water, into which pour slowly, stirring at the same time with a glass rod, 800 grammes of pyrophosphate. When the salt is completely dissolved, filter the liquid and leave to cool. Place in a glass vessel

10 grammes of virgin gold;
30 „ of pure hydrochloric acid;
15 „ of pure nitric acid

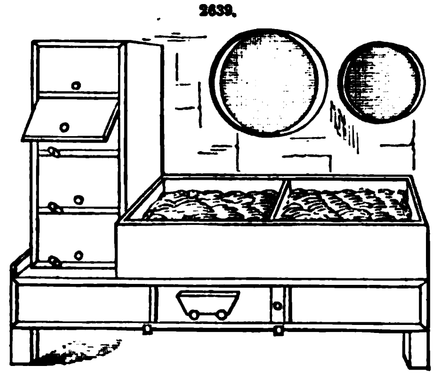
Heat slightly until red vapours are evolved. Then allow the solution to take place, which will give a deep yellow liquid; evaporate this liquid until it has reached the consistence of sirup. When sufficiently evaporated, the liquid will throw off no perceptible vapours, and it will be of a dark crimson colour.

Dissolve the chloride of gold in distilled water, and filter. This filtration serves to separate the chloride of silver which has been formed, owing to the presence of a small quantity of silver, which the purest gold of commerce always contains. The filter must be washed several times to take away all the chloride of gold, and the tenth litre of liquid completed with distilled water. Pour the chloride of gold thus placed in solution into the solution of pyrophosphate to which prussic acid has been added. This latter acid is not indispensable, but it renders the action of the bath regular. The liquid should be colourless; if it has a violaceous tint, it is because too small a quantity of cyanhydric acid has been used. This acid must be added with caution, for an excess of it would render the plating impossible without the aid of a battery.

A bath prepared in the manner described above, gives a very good yellow plating upon copper or brass articles cleaned by the processes already explained. It may be used also to gild silver. For this purpose, the proportion of cyanhydric acid must be slightly increased, and the articles boiled for about half an hour in the liquid so obtained. The thickness of the layer may be increased by moving the articles with a copper or zinc rod.

The gilding of copper may, by this method, acquire a certain thickness, if the article be dipped into a very weak solution of nitrate of mercury before it is placed in the bath. By repeating this operation several times, several successive layers of gold may be deposited, for instead of the gilded surface having no action on the bath, we expose successively a layer of mercury, which is dissolved in the bath, and is replaced on the surface of the object by a fresh quantity of gold.

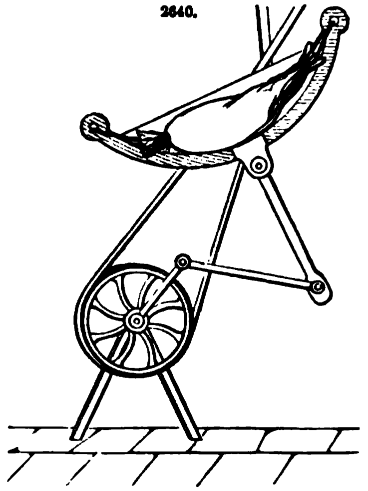
2639.



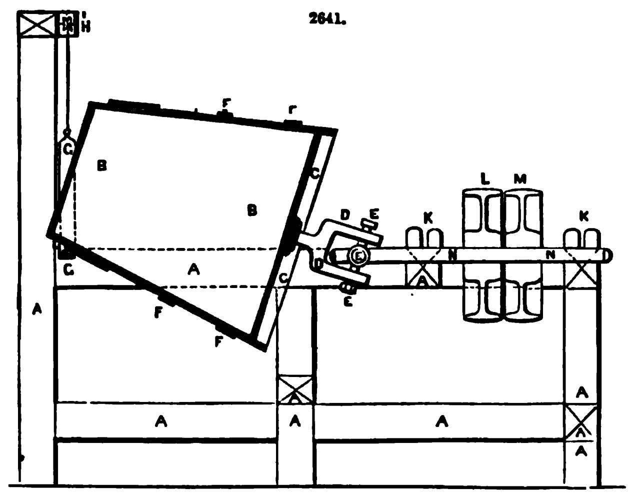
In this way, by means of simple immersion, a plating may be executed capable of rivalling that obtained by means of the battery.

When taken from the bath, the articles are well rinsed and dried in hot saw-dust. If they are hollow, they must be dried in a stove heated up to 70° or 80°. Fig. 2639 represents a small stove with a saw-dust box and metal sieves for separating the saw-dust from small articles. These articles being too small to be brushed are sometimes sifted to render them bright. Figs. 2640, 2641, represent two of this kind of sieves. Their arrangement and mode of action will be seen by the figures.

2640.



2641.



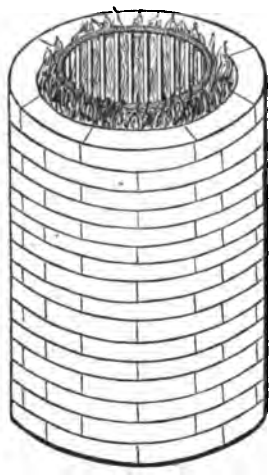
If it happen, which is but too often the case, that on being taken out of the bath the plating is found to be imperfect, either on account of accidents or on account of having neglected some of the precautions we have pointed out, the defect may be remedied by a process called by the French *mise en couleur*.

This consists in covering the defective articles with a mixture of the following salts dissolved in their water of crystallization:—

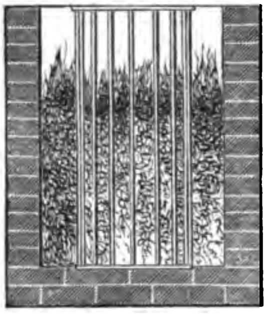
Sulphate of iron	.. ..	Equal parts.
Sulphate of zinc	.. ..	
Alum	.. ..	
Azotate of potash	.. ..	

The articles are then placed in a cylindrical furnace, Figs. 2642 to 2644, having in the middle an empty space into which the heat radiates, and the heating is continued till the salts undergo igneous fusion. The articles are then plunged into water containing sulphuric acid. The salts are rapidly dissolved and the gilding appears with a beautiful warm and uniform tint. If there be parts too highly coloured they may be reduced by striking them with the long bristles of a brush, as represented in Fig. 2645.

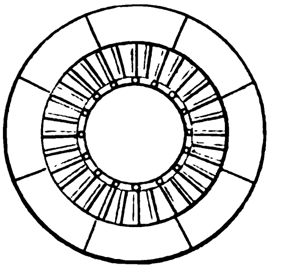
2642.



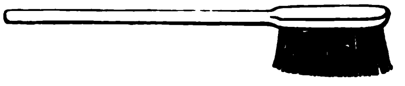
2643.



2644.



2645.



The above process cannot be employed on very fragile articles; the only remedy in this case being the battery.

Such is the method of gilding by immersion adopted by nearly all gilders. It is especially adapted to small articles of jewellery, but it may be employed for larger objects requiring a rich gilding. Skilful operators gild daily thousands of articles by this method, equal in appearance and solidity to those gilded by the electric process.

If we compare Roseleur's to Elkington's bath, we see at once the advantages of the former. Dilution in the one, concentration in the other; rapidity in the former, loss of time in the latter; ability to use nearly all the gold in the pyrophosphate bath, inability to use more than half the gold contained in the bicarbonate; the possibility of depositing at pleasure a small or a large quantity of gold with the one, much narrower restrictions with the other. We say this, not to detract from the merit of the famous English inventor, who was the first to discover a really practical process, but to show the advantages offered by the new method.

With the pyrophosphate bath we may, if we choose, deposit only 0·50 gramme of gold upon a kilogramme of jewellery. Small as this quantity is, it is too large for some manufacturers who desire only the appearance of gold. The following bath will satisfy them;—

Water..	10 litres.
Bicarbonate of potash	200 grammes.
Caustic potash	1·800 kilogramme.
Cyanide of potassium	90 grammes.
Chloride of gold	20 grammes.

This will give a very light, but sufficiently adhesive gilding.

Gilding Aluminium by the Dipping Process.—A process invented by M. Maiche for gilding aluminium, if not of great practical value, possesses interest from a scientific point of view

The bath which he uses is formed of

Gold transformed into ammoniaret	10 grammes.
Cyanide of potassium	20 „
Distilled water	10 litres.

This bath used cold gives an adhesive gilding upon aluminium. The aluminium must be cleansed and rubbed with pounce before it is put into the bath.

Silver Plating by the Method of Dipping.—The oldest method of silvering is by boiling. By this means an exceedingly small quantity of silver might be deposited upon copper. The following is the commonest formula;—

Silver, or chloride of silver	30 grammes.
Powdered cream of tartar	2·50 „
Sea salt	2·50 „

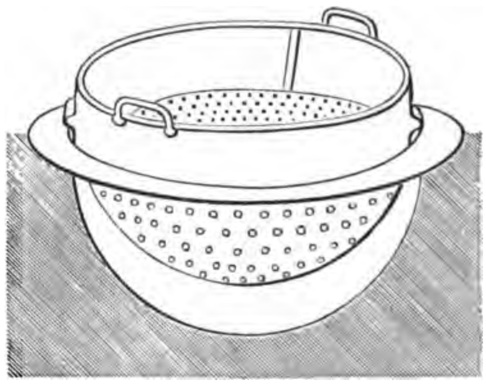
This is made into a paste and kept in an opaque vessel for use. The articles are placed in a kind of basin pierced with holes, and plunged into boiling water contained in the lower basin, Fig. 2646, to which several spoonfuls of the silver paste have been added. The surfaces of the articles

are afterwards brightened by means of the sieve, for this kind of silvering is too slight to bear brushing.

A somewhat thicker plating may be obtained by means of the following solution;-

Distilled water ..	5 grammes.
Caustic potash	160 „
Bicarbonate of potash	100 „
Cyanide of potassium	60 „
Azotate of silver ..	20 „

2646.



This bath is employed chiefly for articles used in carriage building.

All baths of double cyanide of silver and of potassium whiten copper, even when cold, when they have a great excess of cyanide of potassium. To make true silvering baths of them, they have only to be raised to the temperature of 70° or 80°.

The following is one of the formulæ which give the best results;—

Water	20 litres.
Cyanide of potassium	500 grammes.
Azotate of silver ..	150 „

This bath gives a brilliant plating, but rather light, and is especially adapted for those articles of jewellery which are too fragile to bear brushing; the time of immersion should be only a few seconds. The cyanide of potassium employed in this bath consists of about 65 per cent. of real cyanide and 35 per cent. of carbonate of potash.

Silvering with the Cold Bath.—This method, which is comparatively seldom employed, gives the whitest and the most unchangeable plating, and is the most economical. It is not suitable for very thick deposits, but it gives excellent results when only a thin or a moderate thickness of plating is required.

This process, invented nearly twenty years ago by M. Roseleur, and exclusively employed by him, is as yet hardly known to silverers. We, therefore, deem it useful to enter into minuter details.

A liquid bisulphite of soda is first prepared by pouring sulphurous acid into a concentrated solution of carbonate of soda until all the carbonic acid has been displaced by the sulphurous acid. The liquid should be slightly acid, and should redden slightly turnsole-blue paper. It should mark from 24° to 26° on the salinometer.

Having prepared a solution of 100 grammes of nitrate of silver in 1 litre of distilled water, it is poured gently into the bisulphite of soda, stirring at the same time to cause the white precipitate of sulphite of silver, which is formed by the contact of the two metals, to disappear. Being dissolved in an excess of sulphite of soda, this precipitate forms a double sulphite of soda and silver, which constitutes the bath.

By placing copper or brass articles, previously cleansed, into this bath, we may obtain, according to the time of immersion;—

1. A coating as light as we wish, and perfectly white and bright. An immersion of a few seconds is sufficient for this purpose.

2. A more solid plating, such as is required for jewellery. A quarter of an hour is sufficient to produce this result.

3. A dull plating, equal to that produced by the battery, for all articles which do not require a very thick deposit.

The bath must be kept up by adding alternately salts of silver and bisulphite of soda, taking care to put into the bath as much salts of silver as it can easily dissolve. A deposit is gradually formed on the bottom and the sides of the vessel; this deposit must be removed from time to time by pouring off the liquid.

What we have said above with respect to the obtaining, within a certain limit, any thickness of coating, seems to contradict the theory which we have already given. But we have in the case of the bisulphite bath a double phenomenon. At first the deposit is effected by the ordinary reaction —that is, one equivalent of copper is substituted for one equivalent of silver in the solution, whilst one equivalent of silver reduced to the metallic state affixes itself to the copper article. But, besides this action, another is produced, due to the special composition of the bath, and in virtue of which the action of depositing is continued. We have, in fact, brought together sulphite of soda and sulphite of oxide of silver, or, for this latter, sulphurous acid, oxygen, and silver. But silver has little affinity for sulphurous acid and oxygen: sulphurous acid, on the contrary, has great affinity for oxygen, and has a tendency to transform itself into sulphuric acid. We may, therefore, naturally admit that the silver of the sulphite of silver is deposited in a metallic state upon the objects, and that the sulphurous acid of this substance combines with the oxygen to form sulphuric acid, and, consequently, sulphate of soda.

This fact may be represented by the following formula;—

$$SO^2 NaO, SO^2 AgO = SO^3 NaO + SO^2 + Ag.$$

It is difficult to explain, except by the love of routine, why this kind of bath, the advantages of which are so obvious, has not been more generally adopted. Requiring no heating, besides the saving thereby effected, it is always ready for use, and is not restricted by the size of the vessel, as

in the case of hot baths. The battery is not required, and the weight of the silver deposited is always proportional to the time of immersion, a fact which enables us to calculate exactly the value of the plating. Again, bisulphite of soda is a harmless and a not very costly article.

Tinning by the Method of Dipping.—A hot solution of 300 grammes of alum and 10 grammes of protochloride of tin in 20 litres of water gives a bath by means of which a very light deposit of tin may be made upon iron and zinc. This mere pellicle is incapable of preserving the metal from oxidation, and is used only for the commonest objects or as a complement to the cleansing before immersion in other baths. Large quantities of hooks and eyes are tinned by this process.

Antimony Plating by the Dipping Process.—Antimony is firmly deposited upon copper and its alloys, without the aid of a battery, in a bath composed of—water, 10 litres, oxichloride of antimony, 20 grammes. The liquid should be slightly acidulated by means of hydrochloric acid, and used boiling. In this bath articles are in a few minutes covered with a beautiful coating of antimony.

Coppering Zinc by the Dipping Process.—Zinc which is to be gilded must first be covered with a tolerably thick coating of copper. For this operation, recourse is had to two baths which are successively employed. The first, with a cyanide of potassium base, is used with a voltaic battery, and the article receives in this first bath a sufficient coating of copper to preserve it from the acid action of the second, which is an acid solution of sulphate of copper also used with the battery.

The cyanide of potassium bath is too expensive relatively to the low price of the articles manufactured, and therefore much is to be gained by substituting a dipping bath for the cyanide of potassium and the electric baths. The following is suitable for this purpose;—

A quantity of cyanhydric acid, sufficient to produce saturation, is applied to common ammonia at 22°, and into the liquid thus obtained an ammoniacal solution of any salt of copper is poured. By this means a double cyanide of copper and ammonium is formed very suitable for coppering zinc, on the condition that it always remain highly alkaline. The following proportions give the best results·—

Liquid cyanide of ammonium	1 kilogramme.
Distilled water	20 litres.
Acetate of copper	200 grammes.
Ammonia 22°	100 „

The plating thus obtained is of a beautiful light red colour and remarkably adhesive.

Coppering Iron by the Dipping Process.—Iron wire and certain small articles are sometimes coppered by this process. It consists in immersing the articles rapidly in an acid—a weak solution of sulphate of copper. A very thin coating of copper is thus deposited, to which the draw-plate gives a little more adhesion and brightness. If the immersion were not made rapidly the iron would be acted upon by the acid of the bath, and the copper would be reduced under the form of a brownish red mud having no adhesive quality.

Metallic Deposits by Double Affinity.—We denote by this term those deposits which are effected in certain liquids in the presence of two metals, one of which substitutes itself for the metal in solution, whilst the other receives the deposit of the metal which was primitively in solution.

There is really a galvanic action resulting from the contact of two metals in a liquid which exerts a chemical action upon them, but in the majority of cases a special phenomenon seems to be produced of a nature more particularly chemical, for the weights of the metal dissolved and of the metal deposited are not in equivalent atomic proportions.

Nearly all baths by simple immersion act more rapidly when a piece of zinc is plunged into it simultaneously with the object to be plated and in contact with this latter. On the other hand, nearly all galvanic baths give a metallic deposit in the same conditions, only this deposit is slow. Two processes only—Roseleur's method of tinning, and Weill's method of coppering—offer real advantages and are thoroughly practical.

Weill's Method of Coppering.—This process enables us to obtain, without heating, an adhesive deposit of copper upon iron and steel by immersing it in an alkalino-organic bath in contact with zinc. The bath is composed of a salt of copper, held in solution in caustic soda, by the presence of an organic matter, such as tartaric acid, double tartrate of soda and potash, glycerine or albumen.

Experience has shown that the following proportions give the best results;—

Sulphate of copper	350
Seignette's salt	1500
Caustic soda	800

which correspond to two equivalents of tartaric acid for one equivalent of salt of copper.

By dipping successively the baser metals into this solution, we obtain various results, which may be summed up in the three following observations;—

1. The metals whose oxides are insoluble in caustic soda are plated only by means of the contact with zinc.

2. The metals whose oxides are soluble in the fixed alkali, and which form only one salifiable oxide, are covered with a very thin coating, which does not increase with the time of immersion.

3. The metals which may form several salifiable oxides, soluble in the fixed alkali, do not become plated in the solution, and they decompose it in contact with zinc, giving a precipitate of protoxide of copper.

The practical conclusion from these observations is that the really important application of the bath in question consists in depositing, by contact with zinc upon iron and steel, an adhesive coating of copper, of good quality and varying in thickness according to the time of immersion. The thickness of this coating may, in case of need, be increased in the galvanic bath, for the

metal is sufficiently protected against the action of the sulphuric acid by this first coating of copper.

The cleansing of iron is accomplished in the same way for this bath as for others; it is worthy of remark, however, that the cleansing is completed in the bath itself, for the oxide of iron is soluble in the alkalino-organic solution.

The time of immersion varies, 3 to 72 hours. The bath is kept up simply with sulphate of copper and, from time to time, with caustic soda. The Seignette's salt is not decomposed, and remains in the bath almost indefinitely.

By varying the respective proportions of salt of copper and of double tartrate of soda and potash, so as to have only one gramme of tartaric acid to one gramme of salt of copper, we obtain, no longer a good plating, but a series of very curious and permanent colorations which are produced always in the same order, namely, orange, white, light yellow, deep yellow, crimson, green. If the immersion is continued after the green has been produced, the metal assumes a brownish appearance, not pleasing to the eye. These various colourings may be utilized in the decoration of cast-iron objects now extensively used in architectural ornamentation, as they resist sufficiently atmospheric agents.

The alkalino-organic bath dissolves various metallic oxides, and gives deposits of metals other than copper. The action of baths compounded with various oxides is summed up in the following lines taken from the Annales de Physique et de Chimie;—"The metals of the metallic oxides of the formula $m^2 O^3$, which are at the same time susceptible of forming a salifiable protoxide, are capable of being precipitated upon copper from their alkalino-organic solution in contact with zinc and under the influence of heat, a phenomenon which is then accompanied by a liberation of hydrogen; the analogous metals which form only one salifiable sesquioxide, such as alumina and oxide of chrome, are not. Copper is directly reduced from its alkalino-organic solutions by iron, steel, and so on, under the form of an adhesive coating, in contact with zinc and at the ordinary temperature. Under the influence of heat these metals receive, on the contrary, only various colorations which will not resist the action of the brush."

Galvanic action undoubtedly plays an important part in copper-plating; but it seems clear that it is also due in part to a more specially chemical action, for zinc itself becomes plated with copper, and the decomposing action is continued none the less. Again, a very small quantity of zinc and a few points of contact are sufficient to enable the deposit to be effected in good condition. And the quantity of zinc dissolved is far from being proportional to that of the copper deposited.

Tinning by Double Affinity.—Roseleur and Boucher's Process.—This process, which was patented a few years ago by the inventors, gives remarkably good results, and is now widely employed. It is used especially in the manufacture of kitchen utensils, hooks and eyes, pins, and so on. A medal, 80 centimètres in diameter, representing the Emperor Napoleon III., and tinned by this process, was exhibited in the Paris Exhibition of 1867, and such was the perfection of this tin-plating that many visitors took it for silver. An idea of the efficacy of this deposit in protecting iron may be gathered from the fact that several articles, tinned by this process, which had gained a Prize Medal in London in 1862, were again exhibited in Paris in 1867 without having been touched in the meantime.

We will give a description of the process in the words of the inventor;—"The bath may vary greatly in its composition; but the following two formulæ attain the object rapidly and surely. We much prefer the second, however, which offers the single objection of being based on the employment of a salt that all manufacturers do not always obtain from a very regular composition.

"First formula;—

Distilled water	300 litres.
Cream of tartar	3 kilogrammes.
Protochloride of tin ..	300 grammes.

The whole being dissolved gives a colourless solution, but with a strongly acid reaction, which constitutes the bath.

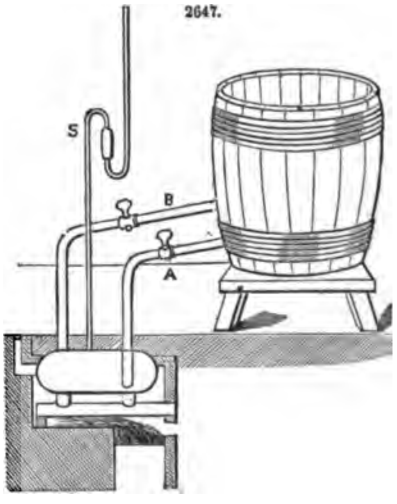
"Second formula;—

Distilled water	300 litres.
Pyrophosphate of potash	6 kilogrammes.
Acid protochloride of tin	600 grammes.
The same, dissolved ..	2·400 kilogrammes.

The whole is dissolved at the same time upon a metal sieve, and after being shaken there remains a clear liquid, which is the bath.

"One of these solutions is placed in a cask staved in at the top, and of sufficient capacity. This cask, Fig. 2647, receives in the lateral part of its base, but at different heights, the two pipes of a small metal boiler fixed over a furnace beneath the bottom of the vat; the pipe A which is on a level with the bottom of the cask reaches, at its other end, nearly to the bottom of the boiler; the pipe B, on the contrary, the one which enters the vat higher up, at 6 or 8 centimètres from the bottom, comes from the top of the boiler. This boiler has a third pipe in S which serves to protect the workmen from an explosion, in case there were an obstruction in the pipes communicating with the cask and the

2647.



boiler. It will be seen that the things being thus arranged, and the liquid filling both the vat and the boiler, if we heat the latter, the liquid which it contains being expanded by the heat, will become lighter and will ascend to the top of the vat by the pipe which enters highest into it, but at the same time the vacuum will be filled with an equal quantity of cold, and consequently heavier liquid, which will enter from the vat into the boiler by the pipe which is inserted at the bottom of the latter. By this means a continual circulating motion is kept up which will constantly bring the coldest portions into the boiler, while the hottest are driven out by virtue of their less density. This method is not designed merely to heat the liquid, but to keep the bath in a state of continual agitation, and to renew as they become exhausted the portions of the liquid which touch the articles to be tinned.

"When it is required to tin large articles, such as culinary utensils, for example, they may, after being cleansed and rinsed, be thrown careless into the bath with some fragments of zinc, or, better still, with some spirals of this metal; these latter injure less by their contact the articles to be tinned. When, on the contrary, the articles are very small, such as pins, hooks, tacks, and so on, they are arranged in beds of 2 or 3 centimètres thick upon pieces of zinc pierced with small holes to allow the passage of the liquid, and provided with a rim to prevent the articles from rolling off. These pieces are let down into the bath by means of numbered chains, in order that they may be pulled out in the opposite direction. These pieces of zinc must be cleaned occasionally.

"The time of the operation may vary from one hour to three, after which the whole is taken out to introduce into the bath 250 grammes of pyrophosphate, and the same quantity of dissolved protochloride of tin. While these salts are being dissolved, the larger articles are brushed, and the smaller moved by means of an iron fork to change the points of contact; the whole is again placed in the bath for at least two hours. These two successive immersions and this minimum time are necessary to give a good tinning. It only remains now to brush the larger objects again, if they are required to be bright, and to sift the smaller ones, and to dry the whole in very hot and dry pine saw-dust.

"If it be observed that the deposit of tin, though abundant, is grey and dull, the bath must be charged once or twice with acid protochloride of tin; if, on the contrary, the deposit is very white, but puffy and of no adhesion or thickness, the acid salt must be suppressed and replaced by drawing off. In this case also, the quantity of salt of tin may be diminished, and that of the pyrophosphate increased.

"When a bath has been used for a long time, it must be drawn off to separate from it the pyrophosphate of zinc which has been formed. When after some years it is quite worn out in consequence of an alteration of the salts, it may be put aside to keep articles in which have been cleaned."

Galvanic Deposits in Thin Coatings.—We come now to that part of the art of coating the baser metals which, whether we consider the wonderful variety of its productions, or the immense quantity of articles it furnishes to commerce, is by far the most important. Gold and silver plating are the most usual of these metallic deposits; and it will be found interesting to examine the successive transformations which have led this art to the degree of perfection in which it now is, and beyond which it seems impossible to go.

Hardly had Volta invented the admirable instrument which has rendered him famous, when it was attempted to apply the battery to the decomposition of metallic solutions. Volta himself, Nicholson, and Cruikshank had applied the battery to the precipitation of metals, but without thinking of obtaining them in the special state which constitutes the qualities of a good metallic deposit. The deposits which they obtained were pulverulent, lamellate or crystallized, but not continuous or adhesive layers.

Brugnatelli, a pupil of Volta's, afterwards his colleague in the University of Pavia, was the first to obtain, in 1802, a deposit of gold and silver offering the aspect of a regular and uniform layer, such as is required for gold and silver plating. Brugnatelli even succeeded in depositing platina; but this metal was reduced to the state of a very fine powder, which required friction to give it brightness and adhesion.

The solutions employed by Brugnatelli were alkaline; they consisted of ammoniarets of gold, silver, or platina, that is, the product obtained by treating the chlorides of gold and platina, or the azotate of silver, by ammonia. There is much obscurity in the descriptions of Brugnatelli, but according to the Journal de Physique et Chimie of Van Mons, his method was as follows:—

"The most expeditious method of reducing, by means of the battery, dissolved metallic oxides, is to make use of their ammoniarets: by placing the ends of two conducting wires of platina into ammoniaret of mercury, the wire of the negative pole speedily becomes covered with small particles of this metal."

"I have recently gilded," says the same chemist in another journal, "in a most perfect manner, two large silver medals, by putting them in communication by means of a steel wire with the negative pole of a voltaic battery, holding them one after the other in ammoniarets of gold recently prepared." . . .

MM. Barral, Chevalier, and Henri, tried to reproduce Brugnatelli's operation by following his descriptions, but with very imperfect results, the nature of the dissolvent employed by the learned Italian not being known. But as there is nothing to lead us to suppose that Brugnatelli wished to envelop the subject in mystery, we are induced to suppose that this dissolvent was the liquid itself in which the ammoniaret was precipitated. And, in fact, if we take a solution of gold in aqua regalis, and if, without evaporating it to get rid of the excess of acid, we pour into it an excess of ammonia, we obtain the precipitate of ammoniaret of gold; but this precipitate redissolves itself in part, especially by the action of heat, in the ammoniacal salts which have been formed. It is, therefore, probable that Brugnatelli's solution was a double chloride of gold and ammonium, and not ammoniaret of gold.

The problem was perhaps already solved from a scientific point of view; but it was far from being solved practically, and many years passed without any serious application being made of it. At length, in 1825, M. de la Rive, of Geneva, resumed the experiments of Brugnatelli, and attempted to decompose chloride of gold by means of the battery. His efforts were unsuccessful, except in the case of platina, the only metal that is not sensibly acted upon by the chlorine set free by the decomposition of the chloride of gold. It was not till 1840, that is, after the labours of M. Becquerel in the matter of applying electro-chemical decompositions to the treatment of ore, that M. de la Rive realized the idea of employing the simple apparatus for the application of gold upon the other metals. The following is his process;—

A very weak solution of gold is placed in a cylinder of gold-beater's skin, which cylinder is placed in a vase full of water acidulated by a few drops of sulphuric acid. In the outer vase is put a piece of zinc which communicates by a metallic wire with the object to be gilded, the object being placed in the cylinder of gold-beater's skin. The solution of gold should be as neutral as possible, and a very weak current must be employed. Notwithstanding these precautions, the gilding is far from perfect, and the process is open to several objections, the chief of which are the slight adhesion of the gold, and the great loss of metal occasioned by the contact of the solution with the skin, and the endosmose which is gradually effected through the membrane causing the gold to be precipitated upon the zinc.

It became necessary, therefore, to discover a better method if galvanic gilding was to be made a useful art. Elsner showed that the defective adhesion was owing to the acidity of the auriferous liquid, and Boettger, profiting by these observations, succeeded in gilding in a double chloride of gold and potassium.

But the complete solution of the problem and the first really practical application of electroplating are due to Messrs. Elkington, of Birmingham. In September, 1840, Henry Elkington took out a patent for gilding copper by means of a solution of oxide of gold in prussiate of potash. At first he employed the simple apparatus in the production of the galvanic current. His apparatus differed from that of De la Rive's in having a vase of porous earth instead of gold-beater's skin. At the same time Richard Elkington patented a method of applying silver by means of the galvanic current and a solution of chloride of silver, in prussiate of potash.

From this time electro-chemical gold and silver plating may be considered to have been discovered. M. de Ruolz followed with the compound apparatus and a large number of solutions, the chief of which are;—

Cyanide of gold dissolved in simple cyanide of potassium.
Cyanide of gold in yellow prussiate.
Cyanide of gold in red prussiate.
Chloride of gold in the same cyanides.
Sulphuret of gold in sulphuret of potassium.

M. de Ruolz attempted also to deposit other metals, and succeeded in depositing brass by the electric process.

If, therefore, the merit of having discovered electro-plating has been wrongly ascribed to M. de Ruolz, since he had been preceded by several months by the Messrs. Elkington, we should be doing him an injustice if we withheld from him the merit of having endeavoured to improve and generalize the processes of the English manufacturers.

MM. Roseleur and Lanaux succeeded in obtaining platina in adhesive coatings of any thickness, and M. Roseleur, by applying phosphates and sulphites to the dissolution of various metallic oxides, rendered thoroughly practical most of the operations of electro-metallurgy.

Many other chemists aided in bringing this beautiful science to the present degree of perfection; but we have said enough to give an idea of how it grew into existence. We will now consider the processes actually in use, prefixing, however, a few words on the galvanic batteries most generally employed.

Batteries.—Almost every day we hear of some *inventor* extolling the merits of a new pile endowed with every imaginable quality. Unfortunately, on testing this wonderful invention, we find in well-nigh every case that no progress whatever has been made, and this negative result is not surprising, for most of these pretended inventors are ignorant of the very rudiments of physics and chemistry. Though there is at the present time a large number of batteries of various systems, three only, Bunsen's, Smee's modified, and Daniell's, are generally employed in electro-plating.

Bunsen's pile is employed whenever a strong current is required. This pile is by far the most frequently used, notwithstanding the objections to which it is open, and which are, chiefly, the cost of keeping it in working order, the employment of nitric acid which emits disagreeable nitrous vapours, and the shortness of its duration. It is hardly necessary to describe this *battery*, which is well known. It will be seen that it is composed of an outer vessel of stone or porcelain, a zinc cylinder, a porous cylinder or cell, and a cylinder of carbon. Ordinary nitric acid is placed in the porous cell, and in the outer cell or containing vessel, water acidulated with two or three hundredths of sulphuric acid, and containing a salt of mercury (1 or 2 per cent.) for the purpose of amalgamating the zinc.

The elements of the *battery* are connected by establishing a communication between the carbon of the first element or cell and the zinc of the second, and so on with the whole. A zinc remains free at one end and a carbon at the opposite end; the articles to be plated are put in communication with the zinc (the negative pole) and the acid with the carbon (the positive pole).

Smee's *battery* modified is employed chiefly in electrotyping; it is less powerful than Bunsen's, but more convenient and less expensive. It consists, as will be seen by merely inspecting, of a gutta-percha trough, having on the inside three vertical grooves. In one of these grooves retort carbon is placed: the other two contain zinc. To put this battery in action, the vessel is filled with water saturated with sea salt, or acidulated with a twentieth of sulphuric acid. Sometimes,

especially in large apparatuses, the carbon is omitted in favour of silvered and platinized plates of copper.

Daniell's battery, which, by means of a happy modification, will give a constant current for several months without requiring any care. To put this battery in action, the porous and the glass vessels are filled with water, and the outer vessel with acidulated water. This battery is especially suited for gilding very small objects, such as watch-works, for example, and for all operations which require only a weak current.

Finally, we have to call attention to a recent invention due to M. Léclanché, and which is very satisfactory both as regards the duration and the regularity of the current. It consists of an outer glass vessel containing sand, chlorhydrate of ammonia, and a very small zinc cylinder; and a porous vessel containing bioxide of manganese agglomerated by a gummy solution, in which is placed a copper rod.

Galvanic Gilding.—Galvanic gilding is accomplished both with and without heat: with heat for articles of small dimensions, such as jewellery and table services; without heat for larger objects, such as clocks and chandeliers.

It was long believed that gilding effected with heat was less resisting than that obtained without heat. The truth is, on the contrary, that with *an equal quantity of gold* the former is much more solid than the latter. The fact of the former method being employed for small articles of little value, in which case small quantities of gold are used, caused the error to obtain credence. The following two formulæ are those oftenest employed in gilding without heat;—

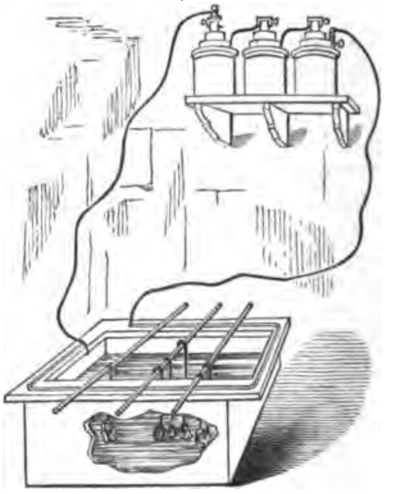
Distilled water	3 litres.
Pure cyanide of potassium	30 grammes.
Virgin gold (as a chloride)	10 „

This bath is prepared by dissolving separately the chloride of gold very neutral and the cyanide of potassium, and then pouring the former solution into the latter. This bath, especially when it has been recently prepared, is a rather bad conductor; and the second formula, which gives more regular results, is to be preferred;—

Distilled water	3 litres.	
Pure cyanide of potassium	25 grammes.	
Carbonate of potash	100 „	
Ammoniaret of gold from	10 „	of gold.

The ammoniaret of gold is prepared by pouring an excess of pure ammonia into a solution of chloride of gold. The precipitate is collected upon a filter, washed, and without drying, for this compound is explosive; the filter is cast into the solution of cyanide of potassium previously prepared; this is boiled an hour and filtered to take away the paper of the first filter. A sufficient quantity of water to make 10 litres is then added, and as soon as the bath is cold it may be used.

2648.



Cold baths are usually placed in wooden troughs, lined with gutta-percha, and of the shape of those shown in Fig. 2648. The positive pole is put in contact with a plate of gold or platina, while the negative pole is in communication with a copper stand supporting the articles to be gilded.

It sometimes happens that objects gilded in the cold bath have an unsatisfactory colour; this may be remedied by dipping the object into a solution of nitrate of mercury and subjecting it to the action of heat, or by rubbing over with boiled borax, then heating it, and finally washing it in water acidulated with sulphuric acid. To avoid all chances of failure, recourse should be had to hot baths whenever practicable.

The following two formulæ give excellent results; the second, however, is to be preferred on account of the regularity of its results, and also because it allows a very thin coating to be deposited, if such be desired, of a very beautiful appearance.

First formula

Distilled water	100 litres.
Gold, as a chloride	180 grammes.
Pure cyanide of potassium	300 „
Carbonate of potash	150 „

Second formula;—

Distilled water	10 litres.
Phosphate of soda	500 grammes.
Bisulphite of soda	150 „
Pure cyanide of potassium	10 „
Gold (as a chloride of gold)	10 „

These baths are employed nearly boiling and with anode of platina. They are kept up by adding from time to time a solution composed of 20 grammes of cyanide of potassium to 10 grammes of gold transformed into ammoniaret, the whole dissolved in a litre of water.

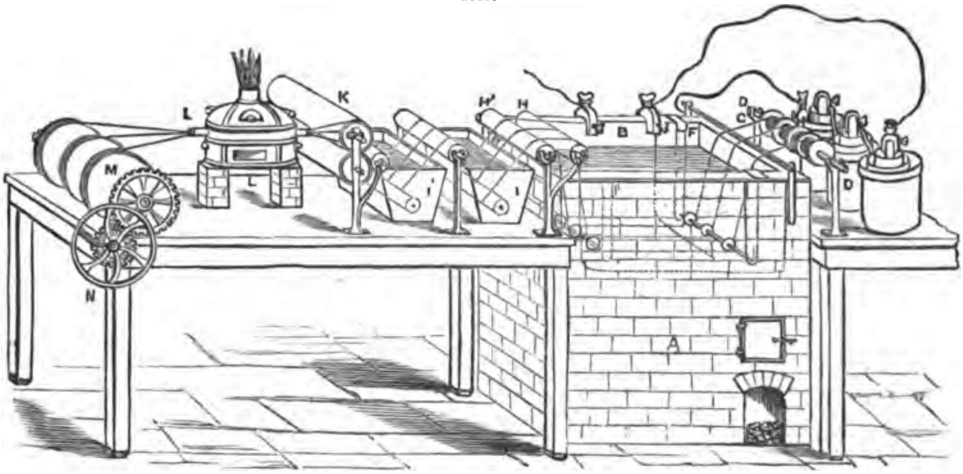
Copper and its alloys, such as bronze and brass, may be gilded in these baths. They serve equally well for silver and platina; but for iron and steel the bath should be composed as follows;—

Distilled water	10 litres.	Phosphate of soda	1200 grammes.
Gold (as a chloride of gold)	20 grammes.	Bisulphite of soda	1200 "
Cyanide of potassium	10 "		

It is better to copper the objects before placing them in the bath. Tin, lead, and zinc, should also be coppered, alkaline baths being employed for that purpose. Aluminium, on the contrary, requires an acid bath of sulphate of copper. It is obvious that however perfect the method of gilding which we have been describing may be, it requires, in certain cases, precautions or particular arrangements for gilding certain objects.

In this way the arrangement represented in Fig. 2649 is employed in the manufacture of fine silver wire or gilded copper wire. This wire is used in the manufacture of lace, and constitutes an

2649.



important branch of industry, carried on chiefly at Lyons. The operation will be understood from the following description of Fig. 2649;—A, the furnace; B, enamelled cast-iron boiler; C, spindle supporting the bobbins; D, copper rod establishing communication between the wires and the negative pole; E, ivory or porcelain rollers; G, platina wires serving as anodes; H, false bobbins; I, vats containing one a solution of cyanide, the other water for rinsing the wire; K, rollers covered with old calico to wipe the wire; L, heated tube in which the wire is dried; M, bobbins set in motion by the crank N, and designed to receive the gilded wire.

After being gilded, the wire is passed through the draw-plate or through the rolling mill, according as it is required to be round or flat.

The gilding of watch-works also needs special preparations. For the details of this operation, which is carried on chiefly in Switzerland and in the Jura, we refer our readers to the excellent work of M. Roseleur, entitled Manipulations Hydroplastiques. We will merely remark that the preparation consists of a silver-plating called grainage, which gives the objects a slightly dull, but very pleasing appearance.

This silvering is accomplished by applying to the objects, with a hard brush, the following mixture;—

Silver powder	30 grammes.
Sea salt	400 "
Cream of tartar	120 "

This formula is one of those employed by M. Pinaire, of Besançon. The articles are afterwards gilded in the ordinary bath. At Paris this kind of gilding is executed with great perfection by M. Bressoud.

In bringing to an end our remarks on electro-plating, we have to mention a process of gilding which partakes at once of the methods of plating by mercury and by the battery. This process, which obtained a first prize in the Paris Exhibition of 1867, is due to M. Dufresne.

Gilding by means of mercury is, as is well known, injurious to the health of the workmen, because they are continually exposed to the action of the mercurial vapours. Indeed, to obtain an equal thickness and a uniform appearance, the workman is obliged to turn the object about over the fire to drive off the mercury by volatilization, and to strike it in all directions with the brush. The consequence of this is that, in spite of the improved draught introduced by M. Darcet, large quantities of mercurial vapours are absorbed by the men.

Again, in certain cases it is found that the electro-plating is not sufficiently thick and solid, and recourse must be had to mercury. In these cases M. Dufresne's process is serviceable; it may be described as follows;—A neutral bath of mercury is prepared by means of nitrate of mercury neutralized by carbonate of soda, and containing cyanide of potassium, and in this bath the objects are subjected to the action of the galvanic battery. They are soon covered with a thick coating of mercury. A thick coating of gold having been deposited on them by the usual means, they are

again placed in the solution of mercury. The mercury is then evaporated by the action of heat, without the assistance of the brush as in the ordinary case of gilding by mercury.

This process offers some advantages from a hygienic point of view, though it becomes necessary to proceed in the usual manner to *equalize* the gilding when a thick plating is required. But it is astonishing that this *discovery* should have obtained a *first prize* on account of its novelty. If the jury had consisted of Frenchmen only, the fact would have been less surprising, for excess of patriotism often leads them to doubt concerning progress which has not been made in France, and keeps them ignorant of what other peoples are doing, but that an *international* jury should have awarded the highest possible reward, in 1867, to a *discovery* described at length in the Annales de Chimie, of St. Petersburg, as long ago as 1851, is really astounding. The whole of the interior of St. Saviour's Cathedral at Moscow was gilded in 1851, under the direction of the Duke de Leuchtemberg, who at that time presided over the Galvanic Institute of St. Petersburg. We have to add, however, that M. Dufresne has renounced an exclusive right to his process.

Electrotyping has been gradually encroaching upon the process of stereotyping, and has almost superseded that process in America. The plan adopted is similar to that of copying woodcuts, namely, to lay a sheet of softened gutta-percha upon the surface of the page of type, and subject it to increasing pressure until it is cold; the gutta-percha copy is then removed, and treated as in copying wood engravings. It would be advisable to try a somewhat softer material for this purpose, such as the mixture of gutta-percha and marine glue. This material takes a sharper and smoother impression than gutta-percha alone, and the deposit spreads over it more rapidly; and, being softer, it would enter more freely and with less pressure between the fine lines of the letters, and still not be sufficiently soft to enter the minute crevices between the body of the types. If a solution of grape-sugar (as used in Drayton's patent process for silvering glass), aldehyde, or other reducing agent, was substituted for the phosphorus solution, for reducing the silver upon the surface of the mould, it would be an advantage, as, besides the dangerous character of the phosphorus, it has an offensive odour, and the copper deposited upon surfaces prepared by it, moreover, is invariably brittle.

The mould may also be prepared for a deposit by blackleading; it will require a first-rate quality of blacklead, and prolonged and attentive brushing, but will then afford a good result. The air-bubbles may be removed when the mould is in the liquid, by directing a powerful upward current of the liquid against them by means of a vulcanized india-rubber bladder, with a long and curved glass tube with a fine orifice attached to it; but the liquid should be free from sediment.

The advantages of electrotyping over stereotyping are numerous; the metal is harder, takes a sharper impression of the mould, and delivers the ink much more readily than type metal, besides being a cleaner process; it also takes up less ink, and consequently the printed pages dry more quickly. Both woodcuts and letter-press have also been copied in plaster of Paris, and the deposit of copper formed upon that; but this material is much inferior to gutta-percha for the process.

Iron and steel wire may be coated with an adhesive deposit of copper, by first immersing them, with their surfaces perfectly clean, in the cyanide coppering liquid, and completing the deposit in the ordinary sulphate solution. The coils should be kept separate from each other in the liquid by suspending them upon a horizontal brass rod, turning it occasionally to cause a uniform deposit. Iron screws and nails may be treated in a similar manner, except that they should be contained in a wicker basket, which is shook about occasionally to produce a uniform deposit.

Copying Daguerreotype Pictures.—An interesting application of the deposition of copper, and one of the easiest to be effected, is that of copying daguerreotype pictures. First solder a wire to the back of the plate near the edge; varnish the back and edges, and allow it to dry; hang it in a clean sulphate of copper solution, which is perfectly free from dust or grease on its surface; and in the course of twenty or thirty hours the deposit will be sufficiently thick to be removed.

The invention of E. A. Jacquin has for its object the preparing of printing surfaces, so as to give them the property of yielding a greater number of impressions than they are capable of yielding in their ordinary state. And the invention consists in covering the printing surfaces, whether intaglio or relief, and whether of copper or other soft metal, with a very thin and uniform coating of steel by means of electro-metallurgical processes. This invention is applicable whether the device to be printed from be produced by engraving by hand, or by machinery, or by chemical means, and whether the surface printed from be the original or an electrotype surface produced therefrom.

In carrying out the invention the solutions of iron employed may be varied, and such is the case in respect to the arrangement of galvanic battery or other source of electric currents used.

It is important that a ferric solution should be employed which will not dissolve or corrode the plate intended to be coated, for if it be attempted to use such a solution, though the iron will be precipitated, it will not only be in a non-coherent state, but the engraved surface itself will be liable to be attacked and injured. It may also be remarked that the coating of iron admits of being removed from a printing surface of copper without injury to the original plate, hence the original plate may, after being coated and used for some time, have the worn coating removed, and then be re-covered with an iron coating as often as may be required; and if care is taken to remove the coating of iron before it has been entirely worn away, the engraved copper or other plate may be made to print a vast number of impressions and yet remain in the original state it was in when it left the hands of the engraver, or was otherwise first produced; the only limit appears to be in the gradual change which takes place in the body of the printing surface by the compression to which it is subjected in the process of printing. Heretofore, in respect to plates engraved in intaglio, if of steel they each yield on the average about 3000 impressions without retouching; if of copper they each yield on an average not more than 800 without retouching; whilst electro-casts of copper obtained from the originals will not on an average each yield even 200 impressions without retouching; in fact, such printing surfaces are so easily worn, that after the first hundred or 150 impressions there is a considerable deterioration in the quality of the work produced. Therefore, for the supply of the number of impressions often required by art associations and others, it has been found necessary to multiply the electro-casts very considerably. In such cases the invention is applicable with con-

siderable advantage, for Bradbury, Wilkinson, and Co., who have successfully applied the process, find that an electro-plate 40 × 22 in. covered or coated with iron has yielded 2000 impressions without its being necessary to remove and renew the iron coating, there being no perceptible difference between the first and last impression, the work on the plate appearing not to have suffered in the slightest degree. Hence in future, by the application of the invention, it will only be necessary to multiply electro-casts to such an extent as may be necessary to ensure the production of prints or impressions with the requisite speed on paper, calico, or other fabrics. At the same time an original engraving on copper would become, when treated according to the invention, more lasting than if engraved on steel. Although original surfaces engraved in relief, and also electro and other casts taken from them, yield a considerably greater number of impressions than those obtained from plates engraved in intaglio, to which the invention has not been applied, nevertheless the invention is applicable with great advantage to such relief printing surfaces, whether of copper or other soft metal, for if they be coated with iron according to the invention they will yield almost an indefinite number of impressions, provided the iron surface be renewed as often as may be necessary, and the printing surfaces be again re-coated.

In carrying out the invention the use of that modification of Grove's battery known as Bunsen's is preferable, because it is desirable to have what is called an intensity arrangement. The trough used for containing the solution of iron in which the engraved printing surface is to be immersed in order to be coated, is lined with gutta-percha, and it is 45 in. long, 22 in. wide, and 32 in. deep. In proceeding to prepare for work, the trough, whether of the size above-mentioned or otherwise, is filled with water in combination with hydrochlorate of ammonia (sal-ammoniac) in the proportion of 1000 lbs. by weight of water to 100 lbs. of hydrochlorate of ammonia. A plate of sheet iron nearly as long and as deep as the trough is attached to the positive pole of the battery and immersed in the solution. Another plate of sheet iron about half the size of the other is attached to the negative pole of the battery and immersed in the solution, and when the solution has arrived at the proper condition, which will require several days, the plate of iron attached to the negative pole is removed, and the printing surface to be coated is attached to such pole, and then immersed in the bath till the required coating of iron is obtained thereto. If, on immersing the copper plate in the solution, it be not immediately coated with a bright coating of iron all over, the bath is not in a proper condition, and the copper plate is to be removed and the iron plate attached and returned into the solution. The time occupied in obtaining a proper coating of iron to a printing surface varies from a variety of causes, but a workman after some experience and by careful attention will readily know when to remove the plate from the solution; and it is desirable to state that a copper plate should not be allowed to remain in the bath and attached to the negative pole of the battery after the bright coating of iron begins to show a blackish appearance at the edges. Immediately on taking a copper plate from the bath great care is to be observed in washing off the solution from all parts, and this may be most conveniently done by causing jets of water forcibly to strike against all parts of the surface. The plate is then dried and washed with spirits of turpentine, when it is ready for being printed from in the ordinary manner. The Bunsen's battery with the trough above described is as follows;—

Twenty elements in series of five; each element is composed of an

Earthen jar, 9 in., and 5¾ in. diameter.
Zinc „ 8 in., 4 in. diameter, and ¼ in. thick.
Porous cell, 8½ in., and 2¾ in. diameter.
Carbon „ 9¾ in. by 2 in. in width, and 1 in. in thickness.

It should be observed that the battery will require attention when in use, as its action will diminish; the acids must therefore be removed gradually by adding fresh materials every two or three days. In order to remove the coating of iron from a printing surface after the iron coating has become worn, a solution which will act on the iron without attacking the printing surface is employed. In removing iron from copper, nitric acid is used diluted with eight parts of water, and care is to be taken to wash off the solution as soon as the iron is dissolved.

Works on Electro-Metallurgy:—A. Smee, 'Elements of Electro-Metallurgy,' 8vo, 1851. C. Walker, 'Electrotype Manipulation,' 18mo, 1851. J. Napier, 'A Manual of Electro-Metallurgy,' crown 8vo, 1860. H. Dircks, 'Contributions towards a History of Electro-Metallurgy,' crown 8vo, 1863. E. Lacroix, 'Études sur l'Exposition de 1867,' 4 vols., royal 8vo, 1867–68. A. Watt, 'Electro-Metallurgy Practically Considered,' 12mo, 1869. G. Gore, 'The Theory and Practice of Electro-Deposition,' crown 8vo. M. de Valicourt, 'Manuel du Galvanoplastie,' 2 vols., 18mo.

ELECTROMETER. Fr., *Électromètre*; Ger., *Electricitätsmesser*; Ital., *Elettrometro*; Span., *Electrómetro*.

See Telegraphy.

ELECTROTYPE. Fr., *Electrotype*; Ger., *Electrischer Abzug*; Ital., *Stereotipia galvanoplastiba*; Span., *Galvanoplastria*.

See Electro-Metallurgy.

ELEVATOR. Fr., *Élévateur*; Ger., *Aufzug*; Ital., *Elevatore*; Span., *Elevador*.

See Lifts; Hoists; and Elevators.

EMBANKMENT. Fr., *Levée de terre*; *Remblai*; Ger., *Erddamm*; Ital., *Argine*; *Terraplen*.

Railroad Cuttings and Embankments.—To find the contents of railway cuttings and embankments with accuracy is one of the most important problems in railroad engineering practice.

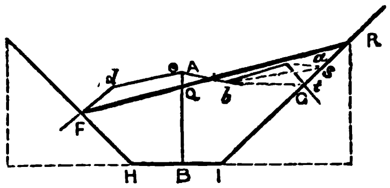
The first object to be acquired in preparing the dimensions of the different cross-sections is to reduce the irregular sections to a level, so that the level section may have the same area as the irregular one.

To draw a line F R, Fig. 2650, so that the area of any cross-section I G *a b c d* F H may be equal to the area of the figure H F R I requires but little engineering or geometrical skill; a thread

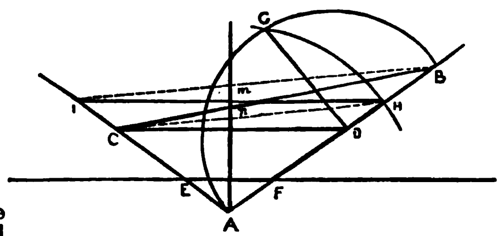
applied across the boundary, when the inequalities are not great, will, in most cases, be sufficient to determine F R. When the variations are great, the parallel ruler will determine F R, in a few seconds, with mathematical accuracy.

Thus draw $a\,s$ parallel to b G, and then draw $s\,b$; then the triangle $b\,s$ G = $b\,a$ G; through b

2650.



2651.

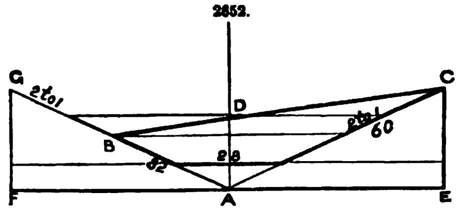


draw a line parallel to $c\,s$, join $t\,c$, as in the last case, and continue the process, until the line F R is determined.

The cross-section is easily reduced to the form F B C F, Fig. 2651; but to draw I H so that it may be parallel to E F, and that the area I H F E = F B C E, has employed the ingenuity of engineers without much accurate practical success, although the object may be thus easily obtained by construction.

On A B describe a semicircle; draw C D parallel to E F, and D G perpendicular to A B; with A G describe the arc G H, through H draw H I parallel to C D; then the area of I H E F = area of B C E F, and A m is the height of the equivalent level cutting required. The same construction will suit for embankments. When this construction is performed accurately, then I B is parallel to C H. Hence the truth of the construction may be tested by taking a parallel ruler and finding whether the lines I B and C H are parallel or not; if these lines be not parallel, the construction must be repeated.

2652.



Example.—Let A B, Fig. 2652, be = 32 ft.; A C = 60 ft.; slopes 2 : 1 (A E : E C :: 2 : 1); required the length of A D.

$$\frac{60 \times 32}{5} = 384 = \text{the square of A D;}$$

therefore, A D = $\sqrt{384}$ = 19·596 ft., $1^2 + 2^2 = 5$, the number above divided by.

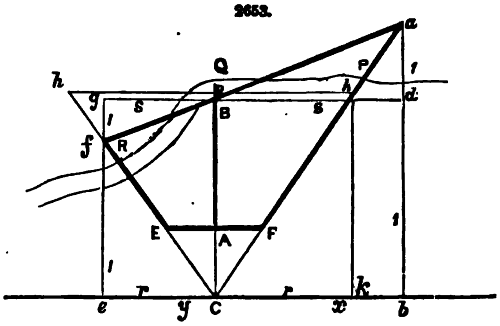
A rule much easier than this cannot be expected. We will apply it to another example in which the ratio of the slopes is expressed in more compound numbers.

Example.—Given A B (Fig. 2652) = 26 ft.: A C = 50 ft.; slopes $1\frac{1}{2}$ to 1 (A F : F G :: $1\frac{1}{2}$: 1); required A D.

$$\frac{3^2}{2} + 1^2 = \frac{13}{4} \qquad \frac{26 \times 50 \times 4}{13} = 400, \text{ the square of A D,} \qquad \therefore \text{A D} = \sqrt{400} = 20.$$

It generally happens that A B, Fig. 2653, the depth in or over the centre A, the breadth of the roadway E F, and the slopes of $f\,a$, F a, f E, are only given, and from which the depth D A of the equivalent level cutting is required. The point B may or not be in the surface of the ground. For example, in Fig. 2650 the point A represents the centre stake, and is in the surface of the ground, while Q, where P R meets A B, is below the surface of the ground; hence, the point B, in Fig. 2653, may be above or below the surface, as the case may be. This remark is important, as the position of the centre stake is so much referred to in setting out the side slopes; and, in fact, it is the point from which all measures are taken. When the height of the centre stake is known above or below the middle of the roadway, in cutting or embanking, the position of B in the line $f\,a$, that equalizes the surface, is not far from the centre stake in most cases. However, $f\,a$ is the line found by construction or otherwise that makes the area E F $a\,f$ = area E F P Q R. Q being the centre stake, and Q B and Q P, Fig. 2653, the lines that are used, to find the places of the side stakes R and P.

2653.



Let the slope of $f\,a$ be represented by s : 1, and of C f or C a by r to 1. Also let B C be represented by m, then, putting x = C b and y = C e, by similar triangles,

$$r : 1 :: x : \frac{x}{r} = a\,b; \qquad s : 1 :: x : \frac{x}{s} = a\,d;$$

$$\therefore m + \frac{x}{s} = \frac{x}{r}, \text{ and hence } x = \frac{r\,s\,m}{s - r} = \text{C}\,b.$$

$$\text{Again, } r : 1 :: y : \frac{y}{r} = ef; \qquad s : 1 :: y : \frac{y}{s} = gf;$$

$$\therefore m - \frac{y}{s} = \frac{y}{r}, \text{ and } y = \frac{rsm}{s+r} = \mathrm{C}e.$$

$$\frac{y}{r} = ef = \frac{sm}{s+r}; \qquad \frac{x}{r} = ab = \frac{sm}{s-r};$$

But on referring to Fig. 2653 it will be seen that

$$\mathrm{C}a^2 = \mathrm{C}b^2 + ab^2; \text{ and } \mathrm{C}f^2 = \mathrm{C}e^2 + ef^2;$$

$$\therefore \mathrm{C}a = \sqrt{\frac{s^2m^2 + r^2s^2m^2}{(s-r)^2}}; \qquad \mathrm{C}f = \sqrt{\frac{s^2m^2 + r^2s^2m^2}{(s+r)^2}};$$

But because the areas of the triangles $\mathrm{C}fa$ and $\mathrm{C}hh$ are equal, and the side, Fig. 2653,

$$\mathrm{C}h = \mathrm{C}h, \qquad \text{Then, } \mathrm{C}h = \sqrt{\mathrm{C}f \times \mathrm{C}a};$$

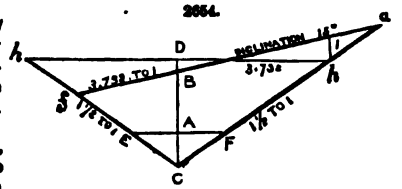
$$\therefore \mathrm{C}h = \sqrt[4]{\frac{s^2m^2(1+r^2) \times s^2m^2(1+r^2)}{(s+r)^2 \times (s-r)^2}} = \sqrt{\frac{s^2m^2(1+r^2)}{(s+r)(s-r)}}.$$

$$\text{But } \mathrm{C}h : \mathrm{CD}\,(hh) :: \sqrt{(1+r^2)} : 1.$$

Hence, $\mathrm{CD} = \dfrac{sm}{\sqrt{(s+r)(s-r)}}$ = the depth of the equivalent level cutting. This computation is easily effected by logarithms, the use of which are recommended when the numbers expressing the ratios of the slopes are compound.

Rule by Logarithms.—From the sum of the logarithms of s and m, take half the sum of the logarithms of s + r and s + r, and the remainder is the logarithm of CD (Fig. 2653), the depth of the equivalent cutting where the side slopes meet.—This rule is the only simple and, at the same time, exact rule that has appeared, spite of the numerous controversies and the equally numerous books the problem has occasioned for many years.

2654.



Example.—Let the roadway E F = 28 ft. wide, with the side slopes of $1\frac{1}{2}$: 1 and the ground to incline transversely at an angle of 15°; with a depth B A, at the station B, of 20 ft.; required A D the depth of the equivalent level cutting F E h h. See Fig. 2654.

Since the cotangent of 15° = 3·732, the inclination of fa is

$$3{\cdot}732 \text{ to } 1; \text{ hence } s = 3{\cdot}732;\ r = 1{\cdot}5. \qquad 1{\cdot}5 : 1 :: 14 : 9\tfrac{1}{3} = \mathrm{AC}.$$

$$\therefore \mathrm{BC} = 20 + 9\tfrac{1}{3} = 29{\cdot}333.$$

3·732	3·732
1·500	1·500
2·232 = $s - r$;	5·232 = $s + r$;
Log. 2·232 = ·3486942	Log. 3·732 = ·5719416
log. 5·232 = ·7186677	log. 29·333 = 1·4673565
2)1·0673619	From 2·0392981
	Take ·5336809
·5336809	
	C D = 32·034 logarithm = 1·5056172
	9·333 = A C
	22·701 = A D, required.

To find A D by common arithmetical calculation is not very difficult, especially when a table of squares, &c., of numbers is employed.

The general expression may be made to assume the form

$$\mathrm{CD} = \frac{sm}{\sqrt{s^2 - r^2}}$$

Example.—Let the road be 36 ft. wide, with side slopes of 2 : 1, the ground to inclin transversely at a slope of 4 : 1; and the depth over the centre of the road, A B = 24 ft.; what is the depth of an equivalent level cutting?

$$2 : 1 :: \frac{36}{2} : 9 = \mathrm{CA}.$$

24 = A B;	m = 33
9 = A C;	s = 4
m = 33 = B C.	132 = $m \times s$.

$$\sqrt{s^2 - r^2} = \sqrt{4^2 - 2^2} = \sqrt{12},$$

the square root of 12 can be found in the table = 3·464, which is taken sufficiently near for the purpose.

$$\frac{132}{3 \cdot 464} = 38 \cdot 103 = \text{C D.}$$
$$9 \cdot 000 = \text{O A.}$$
$$\overline{29 \cdot 103} = \text{A D.}$$

Example.—The breadth of the roadway is 25 ft., with side slopes of 2½ : 1; and a transverse ground slope of 6 : 1 (that is, the slope that equalizes the cross-sectional area); the depth of the station from the centre of the road = 15 ft., what is the depth of a level cutting of equal area?

$$2\tfrac{1}{2} : 1 :: \frac{25}{2} : 5 = \text{A C.}$$

$$15 + 5 = 20 = m. \qquad 6^2 = 36$$
$$6 = s. \qquad (2\tfrac{1}{2})^2 = 6 \cdot 25$$
$$\overline{120} = m \times s. \qquad \sqrt{29 \cdot 75} = 5 \cdot 45.$$

The square root of such numbers as 29·75 can be found by inspecting the table of squares, square roots, &c.

$$29 \cdot 75 \times 4 = 119.$$

The square root of 119 from the table = 10·9087121, the half of which = 5·454356, of which we have taken 5·45.

$$\frac{120}{5 \cdot 45} = 22 \cdot 02 = \text{C D.}$$
$$5 \cdot 00 = \text{A C.}$$
$$\overline{17 \cdot 02} = \text{A D.}$$

This calculation would be very concise, only the work is accompanied by explanations. Without such rendering the work might stand thus, as half the square root of 119 can be taken from the table without calculation.

$$\frac{25}{5} = 5 \qquad 6^2 - (\tfrac{5}{2})^2 = \frac{119}{4}$$

```
       15
       ——
       20
        6
      ————
5·45)12000       {22·02
      1090       { 5·00
      ————        —————
      1100        17·02 = A D.
      1090
      ————
       1000
       1090
```

Example.—The breadth of the roadway is 27·8 ft., with side slopes of 36° 40′ and a transverse equalizing ground slope of 21° 15′; the depth of the station from the centre of the road 45·6 ft.; what is the depth of a level cutting of equal area?

Natural cotangent of 36° 40′ = 1·3432 = r
" " 21° 15′ = 2·5715 =

$s + r = 3 \cdot 9147$

$s - r = 1 \cdot 2283$

$$2\,b = \frac{27 \cdot 8}{2 \cdot 6864} = 10 \cdot 35 = \text{A C.}$$

45·6
10·35
55·95 = m

Log. $r + s$ = ·5926985
log. $r - s$ = ·0893045
2)·6820030
·3410015

Log. m = 1·7478001
log. s = 0·4101865
From 2·1579866
Take ·3410015
log. 65·612 = 1·8169851

65·612
10·350
55·262 = A D,

the depth of a level cutting of equal area with the one defined in the question.

Example.—The breadth of the roadway = 33·7 ft.; the side slopes of an embankment are

19 : 7; and a transverse ground slope of 23 : 3; the depth of the embankment from the centre of the road = 18·4 ft.; what is the depth of the level embankment of equal cross-area?

$$s = \frac{23}{3} = 7\cdot6667 \qquad \frac{33\cdot7}{5\cdot4286} \quad 6\cdot2078$$

$$r = \frac{19}{7} = 2\cdot7143 \qquad 18\cdot4000$$

$$10\cdot3810 = s + r \qquad 24\cdot6078 = m.$$

$$4\cdot9524 = s - r$$

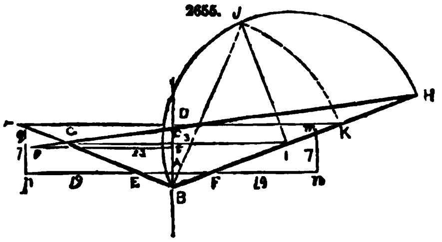
Log. $s + r$ = 1·0162392 | Log. m = 1·3910728
log $s - r$ = ·6948157 | log. s = 0·8846085

2)1·7110549 | From 2·2756813
·8555274 | Take ·8555274

Logarithm of 26·312 = 1·4201539

26·312
6·2078

A D = 20·1042 ft.



Construction.—When many constructions are to be made, section or cross-barred paper will be found very convenient. This paper is ruled, or rather printed from plates of steel or copper, to suit with great accuracy a variety of scales.

Take A C = 18·4 ft. and produce it both ways; draw E A F = 33·7 ft. and perpendicular to A C; A E = A F, Fig. 2655.

Produce A F to n and make F n = 19 on any convenient scale of equal parts, draw m n perpendicular to F n and = 7 such parts, then draw B F m H, and in the same way draw B E G L. Again make C t = 3, and t v perpendicular to it = 23, draw v G C H, and E F G H is the cross-section of the embankment. Draw G I parallel to E F, on B H describe the semicircle B J H, draw I J perpendicular to B H, and make B K = B J, draw K L parallel to E F, then the area F E G H = the level area L K F E and A D = 20·1 ft., as before found by calculation.

To find the Contents of Cutting and Embankments.—Let m be the breadth of the bottom of a level cutting at the rails; a, b, c, d, ... s, the perpendicular heights taken n feet apart; and r : 1 the ratio of the slopes; then

The content of the central part $= \frac{m\,n}{2}\left\{a + s + 2\,(b + c + d\ .\ .\ .\ .)\right\}$; where a and s are the extreme ordinates, and b, c, d, e . . . . the intermediate.

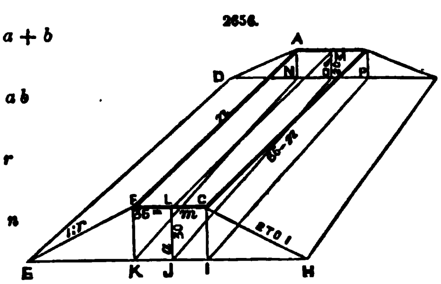
The content of the two slopes $= \frac{n\,r}{3}\left\{(a+b)^2 + (b+c)^2 + (c+d)^2\ .\ .\ .\ . - [ab+bc+cd\ .\ .\ .\ .]\right\}$

Example.—Required the solid content of a cutting or embankment A B C D E F G H, Fig. 2656, whose heights taken at 1 chain of 66 ft. apart are 30 ft. = a, and 20 ft. = b; the width of the rails = 36 ft. = m; the slopes 2 to 1.

In this example r : 1 becomes 2 : 1; n = 66 ft.

The general formula becomes $\frac{m\,n}{2}\left\{a + b\right\} + \frac{n\,r}{3}\left\{(a + b)^2 - a\,b\right\}$, when two ordinates, a and b, are used.

20	$a + b$ =	50
30		50 = $a + b$
50		2500
66	30 × 20 =	600 = $a\,b$
3300		1900
36		2 = r
19800		3800
9900		66 = n
2)118800		22800
		22800
A B P N K F G I = 59400 cub. ft.,		3)250800
		83600 = cubic feet in P B C H I G and A N D E K F together.



83600
59400

143000 = whole content in cubic feet.

This number divided by 27 gives 5296·296, the content in cubic yards. We have used no help to contract the process, in order that the nature of the problem may be thoroughly understood.

Example.—Let the cubical content of the cutting or embankment mentioned in the last example be required, when $n = 100$ ft.

$a = 20$
$b = 30$
2)50
25 × 100 = 2500 =
2500
36
15000
7500
90000 = cubic feet in A B P N K F G I.

50 $= a + b$
50
2500 $= (a + b)^2$
$a\,b =$ 600
1900
2 $= r$
3800
100 $= n$
3)380000 = 126666·66 cub. ft., the content of the two slopes.

90000
126666·66
27)216666·66
8024·7 whole content in cubic yards.

Now observe how easily this result can be obtained when the former 5296·296 is found for a chain of 66 ft.

5296·296
half = 2648·148

Passing two figures to left each time .. { 7944·444 for 99 ft.
79·444
·794
7 }

8024·689

Consequently, if any cubic yards as 90000 be for a 66-ft. chain,

90000
45000
135000
1350
13·5
·1
136363·6

will be the cubic yards for 100 ft. This result is obtained without mental labour.

Example.—Required the cubical content of these cuttings by inspecting the following Tables (I., II., and III.);—

First for $n = 66$ ft.
20
30
2)50
25 × 36 = 900 ft.

From the small Table (I.), for an area of 900 sq. ft., there is given 2199·9999 cub. yds., which may be taken as 2200 cub. yds.

In the large Table (III.), over 20 and opposite 30 will be found

1548
2 $= r$
3096
2200
5296 cub. yds.,

the same whole number of yards as these before found, according to the formula.

TABLE I.—For 66 feet.

1	2·4444444
2	4·8888888
3	7·3333333
4	9·7777777
5	12·2222222
6	14·6666666
7	17·1111111
8	19·5555555
9	21·9999999

When the cubic content in yards for a chain of 66 is known, the content for a chain of 100 is found instantly, as before shown.

5296	
2648	
7944·	for 99 ft.
79·44	
·79	
8024·23	for 100 ft.

When the work is not encumbered by explanations, the ease of application is very apparent, as the following examples will show.

Example.—Let the equivalent level cutting at one end have a particular height J L = 25 ft., Fig. 2656; at the other end, O M = 20. What is the cubical content for lengths of 100 ft., 66 ft., and 50 ft., the roadway 28 ft. wide and the side slopes 1½ to 1?

From Table I.

	25	
	20	
	45	
	14	= half 28.
	180	
	45	
	630	
For 600	1466·6666	
„ 30	73·3366	
	1540·	

Table III.

Opposite 25 under 20	1343·	} $r = 1\frac{1}{2}$
	621·	
	1864	
	1540	
For a length of 66 ft.	3404 cub. yds.	
	3404	
	1702	
For 99 ft.	5106	
	51·06	
	51	
For 100 ft	5157·57 cub. yds.	
	2)5157·57 for 100 ft.	
	2578·78 for 50 ft.	

Hence, if 25 and 20 be the heights of a filling or the depths of a cutting,

	Cub. yds.
For 66 ft., the content =	3404·
„ 100 ft., the content =	5157·5
„ 50 ft., the content =	2578·8

It is easily seen by a practical civil engineer that this is the best and easiest method of finding the solid content of cuttings or embankments yet proposed, whether the chain be 100 ft. long, 66 ft., or 50 ft.

The content for any other distance, as 121·3 ft., is also readily determined, thus;—

For 100 ft.	5157·5
„ 1 ft.	51·575
	121·3
	154725
	51575
	103150
	51575
For 121·3 ft.	6256·0475

Any other length may be applied in the same manner.

Example.—Let 16 ft. be the height of a level filling, which has the same area as the cross-section at this station; 100 ft. from this the height of the level filling is found to be 14 ft.; how many cubic yards of earth does it contain, the ratio of the side slopes ¾ to 1, breadth of the roadway = 32 ft.?

From Table II., which is for finding the content of the central part for lengths of 100 ft., will be found the content of the central part, thus;—

14	
16	
2)30	
15	
32	= breadth of roadway.
30	
45	
480	

For 400	1484·481
„ 80	296·296
Cubic yards	1777·777

TABLE II.—For 100 feet.

1	3·703703
2	7·407407
3	11·111111
4	14·814814
5	18·518518
6	22·222222
7	25·925925
8	29·629629
9	33·333333

Table III.

For the content of the two slopes and a length of 66 feet

Opposite 16 over 14 551
$\frac{3}{4} = r.$
413·25

413·25
half = 206·625
619·875
6·198
61
626·134
Cubic yards 1777·777 for 100 ft.
2403·911 whole content.

Example.—Suppose the equivalent level cutting at one end to be 24 ft., and at the other 36; the roadway 31 ft. wide; the length of the cutting 100 ft., the side slopes $1\frac{1}{3}$ to 1; required the cubical content in cubic yards.

24
36
2)60
30
31 breadth of roadway.
930

From Table II.

For 900 .. .. .. 3333·333
" 30 .. .. .. 111·111
3444·444

From Table III.

Opposite 36 over 24 2229
4
$r = \frac{4}{3}$ 3)8916
For 66 ft. 2972
half = 1486
4458
44·58
·45
For 100 ft. .. .. 4503·03
3444·44
Total content = 8947·47

Example.—Let a cutting be in every respect the same as the last, only the length = 66 ft.; what is the cubical content?

36 + 24 = 60
31 = breadth of roadway.
60
180
2)1860
930

From Table I.

For 900 2200
" 30 .. .. 73·33
2273·33

Opposite 30 over 24 2229
4
$r = \frac{4}{3}$ 3)8916
2972
$2273\frac{1}{3}$
Total content for 66 ft. $5245\frac{1}{3}$

As all the figures employed are set down, it is evident that this plan is superior to any other proposed method, as but one-tenth the mental labour is expended.

What is the content for 12·3 ft. when the content for a length of 66 ft. = 5245·33 cub. ft.?

5245·33
2622·66
7868·00
78·68
78
7947·47 for 100 ft.
79·4747 for 1 ft.

79·4747
12·3
2284241
1589494
794747
Cubic feet 876·53881 for 12·3 ft. length.

Example.—Required the cubical content by the general formula.

$$\frac{m\,n}{2}(a + b) + \frac{n\,r}{3}(a^2 + a\,b + b^2).$$

349														
426	2503													
503	2583													
584	2663													
666	2745													
748	2830													
834	2915													
919	3002													
007	3091													
097	3181													
188	3273													
281	3367													
375	3462													
472	3558													
571	3658													
669	3758													
771	3860													
873	3963													
978	4069													
083	4175													
190	4284													
300	4394													
410	4504													
523	4619													
638	4733													
752	4851													
871	4968													
988	5087													
110	5209													
233	5331	00												
355	5457	46	9097											
481	5583	97	9246	9397										
609	5711	48	9398	9548	9702									
737	5841	00	9550	9702	9858	10012								
868	5971	54	9705	9858	10012	10169	10327							
999	6105	08	9862	10017	10171	10327	10486	10647						
133	6242	66	10020	10172	10328	10488	10647	10809	10972					
268	6374	28	10180	10334	10410	10650	10810	10972	11136	11304				
405	6512	86	10334	10498	10652	10814	10974	11136	11304	11468	11638			
543	6652	52	10504	10660	10818	10978	11140	11306	11470	11640	11808	11978		
683	6794	12	10670	10824	10984	11145	11310	11474	11640	11808	11979	12150	12322	
827	6936	78	10834	10994	11150	11316	11478	11647	11812	11982	12152	12324	12496	12672
31	**32**	**0**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**

To face p. 1390.

$$a = 24;\quad b = 36$$
$$r = 1\tfrac{1}{2};\quad m = 31;\quad n = 100 \text{ ft.}$$
$$\frac{31 \times 100}{2} \times (24 + 36) = 93000$$

$$\begin{array}{r}
24 \\
36 \\
\hline
(a+b)^2 = 60^2 = 3600 \\
a \times b \quad = \quad 864 \\
\hline
a^2 + a\,b + b^2 = 2736 \\
4 \\
\hline
3)10944 \\
\hline
3648 \\
100 \\
\hline
3)364800 \\
\hline
121600 \\
93000 \\
\hline
\text{Content in cub. ft.} = 214600
\end{array}
\qquad\qquad
\begin{array}{l}
27)214600(7948 \\
\;\;189 \\
\hline
\;\;\;256 \\
\;\;\;243 \\
\hline
\;\;\;\;130 \\
\;\;\;\;108 \\
\hline
\;\;\;\;\;220 \\
\;\;\;\;\;216
\end{array}$$

The difference existing between the result obtained by using the Tables and the result given by the formula is but very small for so large a content.

It arises from the results given in Table III. being whole numbers without decimals. In fact, Table III. contains the content in cubical yards to the nearest unit, and the depths of the level cuttings have all the integral values from 1 to 70.

When decimals are annexed, the additional cubical content is found by consulting Table IV. The method of using this Table will best appear from example.

Example.—Let $a = 52{\cdot}6$ ft.; $b = 30{\cdot}4$; the slopes 2 : 1; the breadth of the roadway 36 ft.; length 66 ft.: what is the content in cubic yards?

$$\begin{array}{r}
52{\cdot}6 \\
30{\cdot}4 \\
\hline
83{\cdot}0 \\
18 \;\; = \text{half } 36. \\
\hline
664 \\
83 \\
\hline
1494
\end{array}$$

From Table I.

For 1000	.. .. ..	2444·444
„ 400	.. .. ..	977·777
„ 90	.. .. ..	219·999
„ 4	.. .. ..	9·777
		3651·997

Table III.

Opposite 52 under 30 4208

To find what must be added for decimals (·6) and (·4) employ

Table IV.

$$\begin{array}{r}
52{\cdot}6 \\
2 \\
\hline
105{\cdot}2 = 2\,a \\
30{\cdot}4 = b \\
\hline
135{\cdot}6 = \\
13{\cdot}56 = \dfrac{2\,b + a}{10}
\end{array}$$

The nearest whole number to which is 14.

Opposite 14 and under ·6 68

$$\begin{array}{r}
30{\cdot}4 = b \\
2 \\
\hline
60{\cdot}8 \\
52{\cdot}6 = a \\
\hline
11{\cdot}34 = \dfrac{2\,b + a}{10}
\end{array}$$

The nearest whole number to which is 11.

Opposite 11 and under ·4 36

$$\begin{array}{r}
\left.\begin{array}{r} 4208 \\ 68 \\ 36 \end{array}\right\}\text{add} \\
\hline
4312 \\
2 = r \\
\hline
\text{add}\left\{\begin{array}{r} 8624 \\ 3652 \end{array}\right. \\
\hline
12276
\end{array}$$

12276 cubical content for a length of 66 ft.

TABLE IV

	·1.	·2.	·3.	·4.	·5.	·6.	·7.	·8.	·9.		·1.	·2.	·3.	·4.	·5.	·6.	·7.	·8.	·9.
1	1	2	2	3	4	5	6	7	7	12	10	20	29	39	49	59	69	78	88
2	2	3	5	7	8	10	11	13	15	13	11	21	32	42	53	63	74	85	95
3	2	5	7	10	12	15	17	20	22	14	11	23	34	46	57	68	80	91	103
4	3	7	10	13	16	20	23	26	29	15	12	24	37	49	61	73	86	98	110
5	4	8	12	16	20	24	29	33	37	16	13	26	39	52	65	78	91	104	117
6	5	10	15	20	24	29	34	39	44	17	14	28	42	55	69	83	97	111	125
7	6	11	17	23	28	34	40	46	51	18	15	29	44	59	73	88	103	117	132
8	7	13	20	26	33	39	46	52	59	19	16	31	47	62	77	93	108	124	139
9	7	15	22	29	37	44	51	57	66	20	16	33	49	65	82	98	114	130	147
10	8	16	25	33	41	49	57	65	73	21	17	34	51	68	86	103	120	137	154
11	9	18	27	36	45	54	63	72	81										

If the length = 100 ft. with the other dimensions remaining the same, the content will be

12276
6138

18414·
184·14
1·84

For 100 ft. 18599·98 cub. yds.

These results do not differ from those obtained with mathematical accuracy more than 2 yds., according to the formula.

$$\frac{nm}{2}\left\{a+b\right\}+\frac{nr}{3}\left\{(a+b)^2-ab\right\}$$

$a = 52{\cdot}6$, $b = 30{\cdot}4$. $m = 36$; $n = 66$; all in feet; $r = 2$.

$$\frac{36\times 66}{2}\times(52{\cdot}6+30{\cdot}4)=36\times 33\times 83=98604.$$

52·6
30·4

83·0
83·

249
664

6889 $= (a + b)^2$
$30{\cdot}4 \times 52{\cdot}6 =$ 1599·04 $= a \times b$

5289·96
2 $= r$

10579·92
22 $= \frac{n}{3}$

2115984
2115984

232758·24 $= \frac{rn}{3}(a^2 + ab + b^2)$
98604·

27)331362·26
27

61
54 $\Big\{$ 12273, the true content in cubic yards.

73
54

196
189

72
81

We will next give a model example, merely setting down the numbers employed in the operation.

Example.—Let the depths of a cutting be 39·3 and 37·7 ft.; their distance = 66 ft.; the ratio of the slopes $1\frac{1}{2}$ to 1; what is the content? Bottom width = 33.

$$\begin{array}{r} 39\cdot3 \\ 37\cdot7 \\ \hline 77\cdot0 \\ 33 \\ \hline 231 \\ 231 \\ \hline 2)2541\cdot \\ \hline 1270\cdot5 \end{array}$$

Table I.

For 1000	2444·444
„ 200	488·888
„ 70	171·111
„ ·5	1·222
	3105·666

Table IV.

Opposite 12 under ·3 29

$$\begin{array}{r} 37\cdot7^{*} \\ 2 \\ \hline 75\cdot4 \\ 39\cdot3 \\ \hline \end{array}$$

$$\frac{2b+a}{10} = 11\cdot47$$

Table III.

Opposite 39 over 37 3531

$$\begin{array}{r} 39\cdot3^{*} \\ 2 \\ \hline 78\cdot6 \\ 37\cdot7 \\ \hline \end{array}$$

$$\frac{2a+b}{10} = 11\cdot63$$

Opposite 11 under 7 63

$$\begin{array}{r} 3531 \\ 29 \\ 63 \\ \hline 3623 \\ 3 \\ \hline 2)10869 \\ \hline 5434\cdot5 \\ 3105\cdot66 \\ \hline \end{array} \qquad r = \tfrac{3}{2}$$

Content 8540·16 cub. yds.

Let $a = 7\cdot1$; $b = 6\cdot8$; $c = 5\cdot3$; $d = 7\cdot6$; $e = 11\cdot5$; these depths are at 100 ft. apart; the breadth of the roadway = 30 ft.; and the side slopes 3 : 2, or $\frac{3}{2}$: 1.

$$r = \tfrac{3}{2};\ m = 30;\ n = 100.$$

General formula

$$\frac{mn}{2}\left\{a+e+2\,(b+c+d)\right\} + \frac{nr}{3}\left\{(a+b)^2 + (b+c)^2 + (c+d)^2 + (d+e)^2 - (ab+bc\ cd+de)\right\}.$$

$$\begin{array}{r} 58 \\ 100 = n \\ \hline 5800 \\ 30 = m \\ \hline 2)174000 \\ \hline 87000 \end{array} \qquad \begin{array}{r} b = 6\cdot8 \\ c = 5\cdot3 \\ d = 7\cdot6 \\ \hline 19\cdot7 \\ 2 \\ \hline 39\cdot4 \\ 7\cdot1 = a \\ 11\cdot5 = e \\ \hline 58\cdot0 \end{array}$$

$$\begin{array}{l} (a+b)^2 = (7\cdot1 + 6\cdot8)^2 = 13\cdot9^2 = 193\cdot21 \\ (b+c)^2 = (6\cdot8 + 5\cdot3)^2 = 12\cdot1^2 = 146\cdot41 \\ (c+d)^2 = (5\cdot3 + 7\cdot6)^2 = 12\cdot9^2 = 166\cdot41 \\ (d+e)^2 = (7\cdot6 + 11\cdot5)^2 = 18\cdot1^2 = 327\cdot61 \\ \hline \hfill 833\cdot64 \end{array}$$

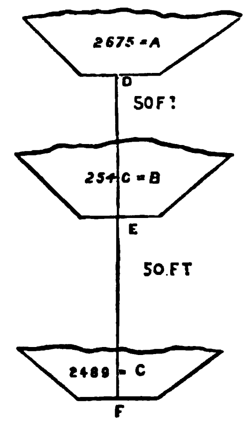
$$\begin{array}{l} 48\cdot28 = a \times b = 7\cdot1 \times 6\cdot8 \\ 36\cdot04 = b \times c = 6\cdot8 \times 5\cdot3 \\ 40\cdot28 = c \times d = 5\cdot3 \times 7\cdot6 \\ 87\cdot40 = d \times e = 7\cdot6 \times 11\cdot5 \\ \hline 211\cdot00 \end{array}$$

$$\begin{array}{r} 833\cdot64 \\ 211\cdot00 \\ \hline 622\cdot64 \\ 100 \\ \hline 62264\cdot \\ \tfrac{3}{2} = r \\ \hline 2)186792 \\ \hline 3)93396 \\ \hline 31132 \\ \text{Add } 87000 \\ \hline 118132 \text{ cub. ft.} \end{array}$$

The formula is convenient when the numbers are small and a table of the squares and products of numbers convenient.

To find the Solid Content of a Railroad Cutting or Embankment, when great accuracy is required.—*Rule.*—Add together the area of two parallel cross-sections, and four times the area of a section half-way between and parallel to them; and multiply the sum by one-sixth of the length measured perpendicularly to the parallel sections, and the product is the solid content required.

2657.



Example.—Let the area of the cross-section A, Fig. 2657, = 2675 sq. ft.; B = 2540 sq. ft.; C = 2489 sq. ft.; the distance D E = E F = 50 ft. or the distance between A and B = 100: what is the content?

$$\begin{array}{r l} 2540 & = B \\ 4 & \\ \hline 10160 & \\ 2675 & = A \\ 2489 & = C \\ \hline 6)\,15324 & \\ \hline 2554\cdot & \\ 100\cdot & \\ \hline 255400\cdot & \text{cub. ft.} \end{array}$$

$$\frac{255400}{27} = 9459 \cdot 2 \text{ cub. yds.}$$

The Tables will determine the content with the same accuracy as the general rule just given, without the middle area being given.

Example.—Let the areas of the two ends of a cutting be 4990 and 1294 sq. ft., the bottom width 30 ft., the length 1·60 chain, and the ratio of the slopes $1\frac{1}{2}$ to 1; required the content of the cutting in cubic yards by referring to the Tables.

In applying the Tables to such examples, the square roots of the areas, to where the slopes meet, must be first extracted, or, which is more easy, taken from a table of square roots.

$1\frac{1}{2} : 1 :: \frac{30}{2} : 10$ ft., the depth below the roadway where the slopes meet, $\frac{30 \times 10}{2} = 150$ sq. ft., the area of the triangle, to be added to the areas of the cross-sections.

$$\begin{array}{r c r} 4990 & & 1294 \\ 150 & & 150 \\ \hline 5140 & \text{and} & 1444 \end{array}$$

the areas of the sections to where the slopes meet. The square roots of these numbers are 71·7 and 38· respectively.

$$\begin{array}{l r} \text{By Table III., for 71 and 38} \quad \ldots\ldots\ldots\ldots & 7483 \\ \text{By Table IV., for } \frac{71 \times 2 + 38}{10} = 18\cdot \text{ and } (\cdot 7) \quad \ldots\ldots & 103 \\ \hline \text{Content to the intersection of slopes} \quad \ldots\ldots & 7586 \\ \text{Take the content from roadway to where the slopes meet} = \frac{150 \times 66}{27} = & 366\frac{2}{3} \\ \hline \text{Content for one chain} \quad \ldots\ldots\ldots\ldots & 7219\frac{1}{3} \end{array}$$

$$7219\tfrac{1}{3} \times 1 \cdot 60 = 11550 \cdot 933 \text{ cub. yds.}$$

Example.—Let the areas of the two ends of a cutting be 3645 and 4036 sq. ft.; the bottom width 27·2 ft.; the length 17·6 ft.; the ratio of the slopes 1·7 to 1; required the content of this cutting by the help of the Tables. $1\cdot 7 : 1 :: \frac{17\cdot 2}{2} : 8$ ft., the depth below the roadway where the slopes meet. $\frac{27\cdot 2 \times 8}{2} = 108\cdot 8$ sq. ft., to be added to the areas of the cross-sections. The solid content of the wedge below the roadway to where the slopes meet, for a chain = 66, in length = $\frac{108\cdot 8 \times 66}{27} = 265\cdot 9$ cub. yds.

It is necessary to make these little preliminary calculations before applying the Tables, in such general examples as the one we have given above.

$$\begin{array}{r c r} 3645 & & 4036 \\ 108\cdot 8 & & 108\cdot 8 \\ \hline \sqrt{3753\cdot 8} = 61\cdot 3; & & \sqrt{4144\cdot 8} = 64\cdot 4. \end{array}$$

When one or both the given depths, or square roots, exceed the limits of Table III., find the

content corresponding to half the two depths, and four times the result will be the content required.

By Table III., for 64 and 61	9550·
Table IV., $\frac{61\cdot 3 \times 2 + 64\cdot 4}{10} = 19\cdot$ and 3	47
$\frac{64\cdot 4 \times 2 + 61\cdot 3}{10} = 19\cdot$ and $\cdot 4$	62·
Content to intersection of slopes	9659·
Content from roadway to the intersection of slopes ..	265·9
	9393·1

Cubic yds.
9393·1 for 66 feet
4696·5

14089·6
140·9
1·4

142·319 for 100 feet
142·319 for 1 foot.

$$142\cdot 319 \times 17\cdot 6 = 2504\cdot 8140,$$

the content in cubic yards for the distance given in the example.

To find the Content of a Railroad Cutting, when the Slopes of the Two Sides are different.—Rule.— Find the content as if one of the slopes were given: take half the result and add it to half the content found by supposing the other slope only given; the sum will be the content required.

Example.—One side of a cutting has a slope of $1\frac{1}{2} : 1$, the other side a slope of $1\frac{1}{4} : 1$; the heights of the equivalent level cross-sectional areas, taken 100 ft. apart, are 13 and 11 ft.; the breadth of the roadway = 30 ft., what is the content in cubic yards?

11
13

2)24

12
30

360

For 300· .. .. 1111·111
60· .. .. 222·222

1333·333 cub. yds. in the central part.

For 13 and 11 in Table III., 353· for 66 feet.

$1\frac{1}{2}$
$1\frac{1}{4}$

$2)2\frac{3}{4}$

$1\frac{3}{8} = \frac{11}{8}$

353
11

8)3883

485·4
4·85
4

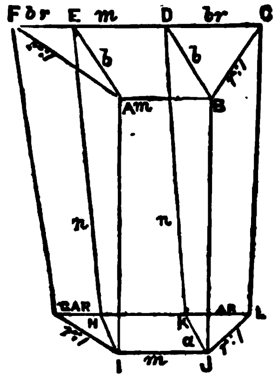
490·3 cub. yds.

Slope $1\frac{3}{8} : 1$, length 100 feet,

1333·3
490·3

Content 1823·6 cub. yds.

2658.



Investigation of the General Formula for Calculating the Content of Cuttings and Embankments.—Let A B C D E F G H I J K L, Fig. 2658, be a railroad cutting: the planes A B C F and L G I J perpendicular to the plane of the roadway I J B A. Then D B = E A = b and K J = I H = a are perpendicular to I A and B J.

The sides J L C B and I G F A slope till their bases are to their perpendiculars as $r : 1$. A E and B D are perpendicular to C F, and J K and I H perpendicular to G L.

B D : D C :: 1 : r, the same proportion holds in the other right-angled triangles A E F, I G H, and K J L.

$\therefore$ E F = D C = br. G H = K L = ar.

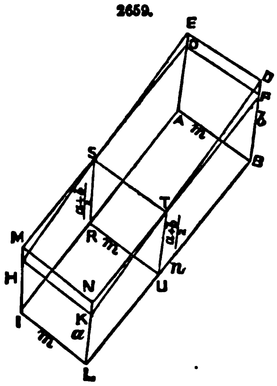
The length of the cutting J B = I A = n, the breadth of the roadway A B = I J = m. Fig. 2658.

The two slopes of Fig. 2659 put together make up the frustum of a pyramid F B C L J G, represented in Fig. 2660. The centre part E D B A I F is given in Fig. 2659, the content of which we will find first.

Let the plane R S T U, Fig. 2659, be parallel to the ends and half-way between them; and

M S O P T N parallel to the road plane A B I J; then the solid I H E D K J = the solid I M O P K J $= \frac{a+b}{2} \times m \times n = \frac{mn}{2}(a+b)$.

2659.



2660.

From this formula Tables I. and II. are calculated, taking $n = 66$ and $n = 100$, and dividing by 27 to reduce the content to cubic yards. We will next find the content of the two slopes, Fig. 2660.

$b - a : n :: a : \frac{na}{b-a} = JQ$. $BQ = n + \frac{na}{b-a} = \frac{nb}{b-a}$. $b^2 r$ = area of the triangle B C F.

$$\tfrac{1}{3} \times \frac{nb}{b-a} \times b^2 r = \text{content of the pyramid FBCQ} = \frac{nr}{3}\left(\frac{b^3}{b-a}\right).$$

Area of the triangle J G L $= a^2 r$, hence the content of the pyramid O G L J =

$$\tfrac{1}{3} \times \frac{na}{b-a} \times a^2 r = \frac{nr}{3}\left(\frac{a^3}{b-a}\right).$$

Consequently, the solid content of the frustum J G L C F B =

$$\frac{nr}{3}\left(\frac{b^3 - a^3}{b-a}\right) = \frac{nr}{3}(b^2 + ab + a^2) = \frac{nr}{3}\left\{(a+b)^2 - ab\right\}.$$

From this expression Table III. has been calculated, taking $n = 66$ ft. and dividing by 27 to reduce the content to cubic yards. The general formula is readily found by taking the sum of the expressions.

$$\frac{mn}{2}(a+b) + \frac{nr}{3}\left\{(a+b)^2 - ab\right\}$$

$$\frac{mn}{2}(b+c) + \frac{nr}{3}\left\{(b+c)^2 - bc\right\}$$

$$\frac{mn}{2}(c+d) + \frac{nr}{3}\left\{(c+d)^2 - cd\right\}$$

&c. + &c., which becomes

$$\frac{mn}{2}\left\{a + x + 2(b + c + d \ldots) +\right.$$

$$\left.\frac{nr}{3}\left\{(a+b)^2 + (b+c)^2 \times (c+d)^2 + \ldots . - [ab + bc + cd + \ldots .]\right\}\right.$$

the general formula that we proposed to demonstrate. We will add an example that often occurs in practice; when cuttings or embankments are measured after the work is done, the sides have different slopes from one another, and from those intended to be given. To find the content of such, the following rule may be useful.

Rule.—Find the content of the centre portion, as in the preceding examples; in finding the content of the two slopes, employ half the sum of the ratios (the consequents being unity), instead of the constant ratio used in other cases.

Example.—Let the bottom width = 36 ft.; the depths of the level equalized cross-sections = 20 and 30 ft. respectively; one of the side slopes $1\frac{1}{2}$ to 1, the other 2 to 1; what is the content, in cubic yards, for a length of 100 ft.?

$$\begin{array}{l} 2 : 1 \\ 1\frac{1}{2} : 1 \\ \hline 2)3\frac{1}{2} \\ \hline 1\frac{3}{4} : 1 = r : 1. \end{array}$$

$$\frac{36 \times 100}{2} \times (20 + 30) = 90000 \text{ cub. ft. in the central part.}$$

```
      20
      30
      --
      50² = 2500 =     + b)²
  20 × 30 = 600
          ----
          1900 = a b + a² + b²
           100
          ------
          190000
               7    r = ⅞
          -------
       4)1330000
          -------
        3)332500
          -------
          110833·3 cub. ft. in the side slopes.
           90000·
          --------
       27)200833·3(7438·2
          189
          ---
           118
           108
           ---
            103
             81
            ---
             223
             216
             ---
              73
              54
```

By the Tables.—Table III.—For 30 and 20 will be found 1548; this is for a length of 66 ft.

```
              1548
               774
              ----
for  99 ft.   2322
               23·22
                ·23
              -------
for 100 ft.   2345·45
                 7       r = ⅞
              -------
        4)16418·15
              -------
              4104·54
              8333·33 found in Table II. for 9000.
              -------
Cubic yards   7437·87

   20
   30
   --
 2)50
   --
   25 × 36 = 9000.
```

By inspecting the Tables the content is found to be 7437·87 cub. yds.; by the formula the content is 7438·2 cub. yds.; the difference is less than half a cubic yard.

Side Depths and Side Stakes.—When the centre stumps of a railroad have been put down, which are usually at the distance of one chain, the line must next be levelled, and the number of the stumps entered in the level-book in a vertical column; and opposite each number, in another column, the depth of the cuttings or embankments; and in a third column, the horizontal half-width of the surface cuttings. But every engineer has his peculiar method of keeping a field or level book.

To set out the width of cuttings, when the surface of the ground is laterally level, and at a given height above the level of the intended railroad, the ratio of the slopes being given, let A B D H, Fig. 2661, be the cross-section of a cutting, the ground H D parallel to the bed of the

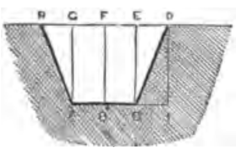
road A B; put C F, the height, in the centre of the road $= h$, and the breadth of the road-bed A B $= b$; the slope of the side A H or B D is generally expressed by the ratio of the base B I to the perpendicular I D; let B I : I D $= m : n$, then the slopes are said to be $m : n$, or $\frac{m}{n}$.

In this case, as it is supposed the ground H D is level, the distance from the centre F to the side stakes D and H will be expressed by $\frac{1}{2} b + \frac{m}{n} h$.

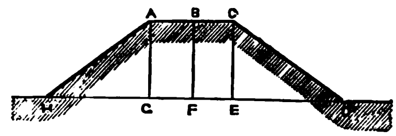
Example.—Let the bottom width A B = 28 ft., the depth of the cutting C F = 16 ft., the slopes 5 : 4; that is, B I : I D = 5 : 4; required the distance of the side stakes H and D from the centre F.

$$\text{H F} = \tfrac{1}{2} \text{ of } 28 + \tfrac{5}{4} \text{ of } 16 = 34 = \text{F D}.$$

2661.



2662.



Example of embankment, when the surface of the ground is laterally level, Fig. 2662. Suppose the breadth of the roadway A B = 32 ft.; the height of the embankment C F = 20 ft., and the ratio of the slopes 6 to 5, that is, D E : E B = 6 : 5; required the distance of the side stakes H and D from the centre F.

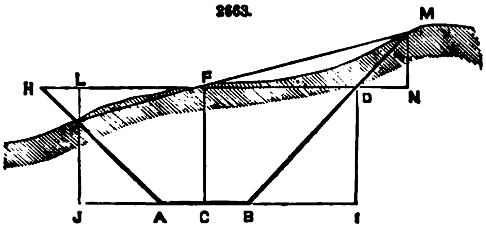
$$\text{H F} = \tfrac{1}{2} \text{ of } 32 + \tfrac{6}{5} \text{ of } 20 = 40 = \text{F D}.$$

The slope given to the sides of either cuttings or embankments varies with the material through which the road has to pass.

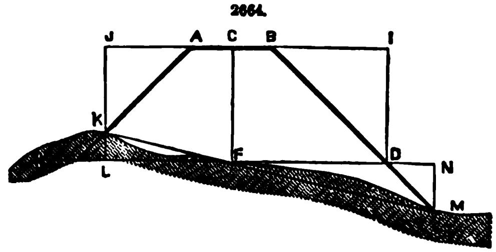
When B I = I D, Fig. 2661, the slope is said to be 1 : 1. The slope is said to be a rise of 2 to 1 when I B = twice I D. In close-jointed rock the ratio varies from 1 : 4, to 1 : 2. In soft or loose-jointed rock, or stiff clay, the ratio varies from 1 : 1, to 3 : 2. If the road passes through moist springy ground or loose sand, the ratio of the slope varies from 2 : 1 to 5 : 2. Should the ground rise from F to M, Fig. 2663, the slope stake must be set out farther, as at M. Let the additional height M N $= p$, then D N $= \frac{m}{n} p$. And if the ground falls from F to K, a distance L K $= q$, the slope stake must be set farther in at K, a distance H L $= \frac{m}{n} q$.

$$\therefore \text{ F N} = \tfrac{1}{2} b + \frac{m}{n} h + \frac{m}{n} p. \qquad \text{F L} = \tfrac{1}{2} b + \frac{m}{n} h - \frac{m}{n} q.$$

2663.



2664.



It often happens that p and q are unequal. Setting slope stakes for embankments resembles setting them for excavations, only a rise from the centre F with excavations corresponds to a fall with embankments; in fact, an embankment is a cutting inverted. Fig. 2664 represents an embankment, and is Fig. 2663 inverted. The rise at K is nearer the centre F, than H on the level, in an embankment, Fig. 2664; while the fall at K is nearer the centre F, than H on the level with F, in an excavation, Fig. 2663.

Example.—In the cutting, Fig. 2663, and in the embankment, Fig. 2664,

Let A B $= b =$ 30 ft. K L $= q =$ 4 ft.
C F $= h =$ 18 ft. $m : n = 3 : 2$.
M N $= p =$ 6 ft.

$$3 : 2 = \text{B I} : \text{I D} = \text{A I} : \text{J K} = \text{D N} : \text{N M} = \text{H L} : \text{L K}.$$

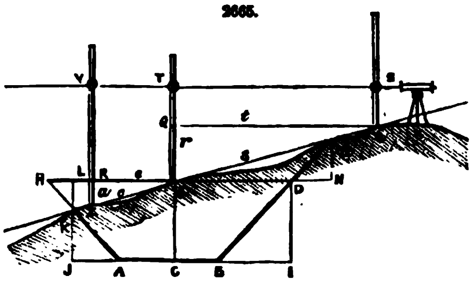
Consequently,

$$\text{F N} = \frac{30}{2} + \frac{3 \times 18}{2} + \frac{3 \times 6}{2} = 51 \text{ ft.} \qquad \text{F L} = \frac{30}{2} + \frac{3 \times 18}{2} - \frac{3 \times 4}{2} = 36 \text{ ft.}$$

As the ground continues to slope up or down from F, the centre stake, the positions of M and K are often determined on the ground by a series of trials, or fudged out in an office by some clumsy mechanical construction or other. To avoid guessing, or rule-of-thumb operations, we will lay down a practical exact plan by which the positions of the side stakes K and M may be easily found. The

positions of D and H on a level with F, the centre stake, can be accurately calculated when the height C F, breadth A B, and ratio of B I to I D are given, therefore it is known, very nearly, where the lines A K and B M strike the surface of the earth. And as F K and F M are seldom in the same straight line, it is more accurate to find the ratio of F L to L K as well as the ratio of F N to N M, Fig. 2665. When these ratios are known, which may be readily found by a level and target-rod, the distance of M from F and of K from F are easily calculated.

2665.



In the neighbourhood of M and K there are always short spaces before or behind M and K, in the directions of the lines K F and F M, and it does not matter how irregular the surface is between these points. It is not necessary that the spaces before or behind K and M are level or not, so that they are nearly in the directions of F M and F K. Set up and adjust the level at any convenient place X, outside the cross-section; place the target-staff at Y, as near as you are able to judge to the required point M; read off the height S Y; remove the staff to the centre stake F, and read off the height F T; the difference between S Y and F T will give Q F, which put $= r$, measure Y F, and put $s =$ Y F. If the distance Q Y be not great, it may be measured by the same tape or chain that takes the length of F Y; or Q Y may be calculated, for Q Y $= \sqrt{s^2 - r^2}$, which put $= t$ to make the reasoning more concise.

Then the three sides of the triangle Q F Y become known; this triangle is similar to the triangle F N M, and hence

$$\mathrm{FN : NM :: } t : r, \qquad \mathrm{FN : FM :: } t : s, \qquad \mathrm{FM : MN :: } s : r;$$

because the three sides of the triangle, Y F, Q F, Q Y, are respectively represented by the three known quantities, s, r, t. Two of these quantities, s and r, may be measured in links or feet on the ground, and the third side may be measured or calculated according to the circumstances of the case. Again, place the target-staff at Z as near the required point K as you are able to judge; but it does not matter where it is placed, as I have before observed, so that it is in the line F K. Then read off the height Z V without changing the position of the instrument at X; from the height Z V take T F, the remainder Z R is one of the sides of the triangle F Z R; put this known height Z R $= a$; measure Z F with a tape or chain, and put it $= c$; R F may be measured and put $= e$, or calculated, for $e = \sqrt{c^2 - a^2}$. As on the other side of the centre F, the triangle F R Z is similar to the triangle F L K. Hence F K : K L : L F $= c : a : e$.

To render this method of proceeding as clear as possible we have dwelt on every point of the process, so that there could be no misunderstanding. This subject has been treated by writers in a most slovenly manner; and by most of the empirical rules laid down by them it takes three or four trials to determine the position of a side stake.

$$\text{Let } \mathrm{KF} = x \text{ and } \mathrm{FM} = y. \qquad \mathrm{AB} = b;\ \mathrm{FC} = h;\ \mathrm{BI : ID} = m : n.$$

And as we have just found by the level and target-staff that

$$\mathrm{FN : NM} = t : r, \qquad \mathrm{FM : FN} = s : t;$$

Also,

$$\mathrm{FL : LK} = e : a, \qquad \mathrm{FK : KL} = c : a.$$

We have selected these measures in the most general manner, in order that the result may embrace all like cases.

$$c : a :: x : \frac{ax}{c} = \mathrm{KL}. \qquad \mathrm{KL : LH = KJ : JA} = n : m; \qquad \therefore \frac{ax}{c} : \mathrm{LH} :: n : m; \text{ or } \frac{amx}{cn} = \mathrm{LH}.$$

$$\mathrm{FH - HL = LF}. \qquad \mathrm{FH} = \tfrac{1}{2}b + \frac{mh}{n}; \qquad \therefore \mathrm{LF} = \tfrac{1}{2}b + \frac{m}{n}h - \frac{amx}{cn}$$

$$c : e :: x : \frac{ex}{c} = \mathrm{FL} \qquad \therefore \frac{ex}{c} = \frac{b}{2} + \frac{mh}{n} - \frac{amx}{cn} \qquad \therefore x = \frac{c(nb + 2mh)}{2(en + am)};$$

and hence the exact distance of the side stake K from the centre F becomes known.

$$s : r :: y : \frac{ry}{s} = \mathrm{MN}. \qquad \mathrm{BI : ID = DN : NM} = m : n; \qquad \therefore n : m :: \frac{ry}{s} : \frac{mry}{ns} = \mathrm{DN}.$$

$$\mathrm{FD + DN = FN}. \qquad \mathrm{FD} = \tfrac{1}{2}b + \frac{mh}{n}; \qquad \therefore \mathrm{FN} = \frac{b}{2} + \frac{mh}{n} + \frac{mry}{ns}; \text{ but,}$$

$$s : t :: y : \frac{ty}{s} = \mathrm{FN}; \qquad \therefore \frac{ty}{s} = \frac{b}{2} + \frac{mh}{n} + \frac{mry}{ns} \qquad y = \frac{s(nb + 2mh)}{2(nt - mr)};$$

and hence the exact distance of the side stake M is readily determined.

Example.—Given the breadth of the roadway A B = 28 ft.; the height of the centre stake C F = h = 24 ft.; the ratio of the slopes A H, B M, or B I : I D = 3 : 2. In a surface distance F Y = 60 ft. $= s$. A rise F Q = 7 ft. $= r$, is found by the level and target-staff; in the surface distance, F Z = 50 ft. $= c$, a fall R Z = 4 ft. $= a$ is found. Required the points K and M where the surface of the ground intersects the slopes that form the road. The solution of this problem and of this first

example are given at full length, in order that the ground-work of the practical rule, to be given presently, may be well understood.

$$\text{F M} : \text{F N} : \text{M N} = s : \sqrt{s^2 - r^2} : r,$$

$$\text{F K} : \text{F L} : \text{L K} = c : \sqrt{c^2 - a^2} : a$$

$$60^2 = 3600$$
$$7^2 = 49$$

$$t = \sqrt{s^2 - r^2} = \sqrt{3551} = 59{\cdot}59$$

$$50^2 = 2500$$
$$4^2 = 16$$

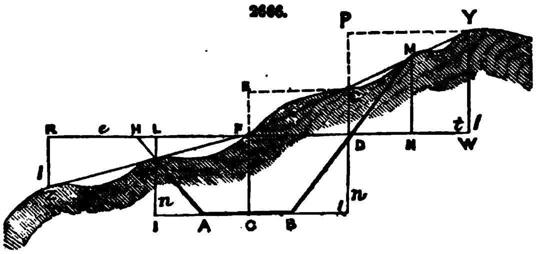
$$e = \sqrt{c^2 - a^2} = \sqrt{2484} = 49{\cdot}84$$

$$x = \frac{50\,(2 \times 28 + 2 \times 3 \times 24)}{2\,(49{\cdot}84 \times 2 + 4 \times 3)} = \frac{10000}{223{\cdot}36} = 44{\cdot}8 \text{ ft.} = \text{the distance from F to K.}$$

$$y = \frac{60\,(2 \times 28 + 2 \times 3 \times 24)}{2\,(59{\cdot}59 \times 2 - 7 \times 3)} = \frac{12000}{196{\cdot}36} = 61{\cdot}11,$$

the distance from F to M. Although this calculation is simple and extremely accurate, yet the generality of practical men require rules that can be applied without entering into the reasoning of the matter in every particular case and example. To suit this class of practitioners we will lay down one or two other methods of finding the values of x and y.

2666.



In Fig. 2666, by the use of the level and target-staff, as described in Fig. 2665, let the rise from the centre stake F, in the direction F Y, be determined; which represent by the ratio $t : 1$ That is, F W : W Y : t : 1.

In the same manner, by placing the target-staff at Z, in the neighbourhood of K, find the fall from the centre stake F, so that F, K, Z, may be in the same straight line, or nearly so; in general terms this ratio may be represented by e to 1, that is, F R : R Z :: e : 1. Before going on the ground to set out side stakes, the lines of the figure H A B D are known; the horizontal half-breadths F D, F H, are found from the height F C, and the breadth of the roadway A B being given. When the positions of H and D are known, it is not difficult to select some points, Z and Y, near them to ascertain the slope of the ground. In finding the half-breadths F D and F H, the ratio of B I to I D is also given; this ratio may be represented by $1 : n$, that is,

$$\text{B I} : \text{I D} = 1 : n; \qquad \text{D N} : \text{N M} = 1 : n; \qquad \text{H L} : \text{L K} = 1 : n.$$

Put v = H L, then $1 : n :: v : nv$ = L K.

Put H F = d = F D, the half horizontal breadth, through the centre stake F.

$$e : 1 :: d - v : \frac{d - v}{e} = \text{K L}; \qquad \therefore\ nv = \frac{d - v}{e} \text{ and } v = \frac{d}{ne + 1}$$

Again, put D N = z, then

$$1 : n :: z : nz = \text{M N};$$

$$\text{and } t : 1 :: d + z : \frac{d + z}{t} = \text{M N}.$$

$$\therefore\ nz = \frac{d + z}{t}, \text{ and } z = \frac{d}{nt - 1}.$$

From which the following simple practical rule may be deduced.

Rule.—When the ground rises from the centre, increase the horizontal half-breadth, divided by the half-breadth by the product (less one) of the numbers that express the ratio of the rise and the ratio of the slope, and the horizontal distance of the side stake is determined. When the ground falls from the centre, decrease the horizontal half-breadth, by the half-breadth divided by the product (plus one) of the numbers that express the ratio of the rise and the ratio of the slope; and the horizontal distance of the other side stake is found.

Example.—Given the breadth of a railway A B = 30 ft.; the height C F = 26 ft.; the side slopes 1 : 2 (B I : I D :: 1 : 2); the rise of the surface from F to Y = 1 in 20 (F W : W Y :: 20 : 1). The fall from F to D = 1 in 36; required the horizontal distances F N and F L, where the surface of the ground intersects the side slopes of the railroad.

H F = $\frac{30}{2} + \frac{1}{2}26$ = 28 = F D, half the horizontal breadth meeting the side slopes on a level line through F. The horizontal distance F W may be measured in lengths E G, P Y, when the surface is irregular.

$$2 \times 20 - 1 = 39, \text{ and } \tfrac{28}{39} = {\cdot}72 \qquad \therefore\ \text{F N} = 28{\cdot}72 \text{ feet.}$$
$$2 \times 36 + 1 = 73, \text{ and } \tfrac{28}{73} = {\cdot}38, \qquad \therefore\ 28 - {\cdot}38 = 27{\cdot}62 = \text{F L.}$$

This calculation is so plain and simple, that the positions of the side stakes are found in a few seconds. It should be noticed that in the ratios of the slopes, and inclination of the ground, unity is taken for the base of the side slopes, but for the perpendicular of the rise or fall of the ground.

Side Depths and Side Stakes.—In an embankment, Fig. 2667, given the breadth of the roadway A B = 32 ft.; the height C F = 18 ft.; the side slopes as 1 to $\frac{2}{3}$ (B I : I D :: 1 : $\frac{2}{3}$); the fall of the surface from F to M = 1 in $26\frac{1}{2}$ (F N : N M :: $26\frac{1}{2}$: 1); the rise of the surface from F to K to be the same as the fall, which is very often the case. Require the horizontal distances F N and F L, where the surface of the ground will meet the rise and slopes of the road.

$$DF = \frac{32}{2} + \frac{3}{2} \times 18 = 43 = FH. \qquad 26\tfrac{1}{2} \times \tfrac{2}{3} = 17\tfrac{2}{3}$$

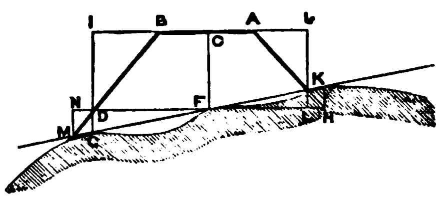
take 1 → $16\frac{2}{3}$

$$\frac{43}{16\frac{2}{3}} = \frac{129}{50} = 2 \cdot 58, \quad 43 \textit{ plus } 2 \cdot 58 = 45 \cdot 58 = FN.$$

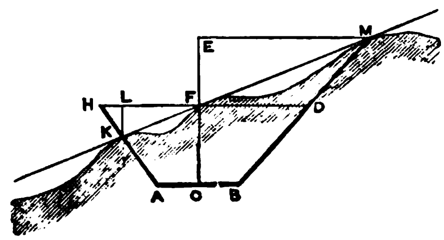
$$\frac{43}{18\frac{2}{3}} = \frac{129}{56} = 2 \cdot 3, \text{ and } 43 \textit{ minus } 2 \cdot 3 = 40 \cdot 7 = F\_.$$

With embankments the rise answers to the fall in cuttings, by inverting Fig. 2663 it becomes Fig. 2664; hence the rule given for cuttings is easily made to answer for embankments.

2667.



2668.



In a cutting, Fig. 2668, given the breadth of the roadway A B = 28 ft.; the height C F = 20 ft.; the ratio of the side slopes 1 : $\frac{1}{2}$; the inclination of the surface of the ground at the cross-section, taken by a theodolite = 14°, that is, the angle M F D = H F K = 14°. Required the horizontal distance E M and F L, where the surface of the ground meets the side slopes.

$$90° - 14° = 76°.$$

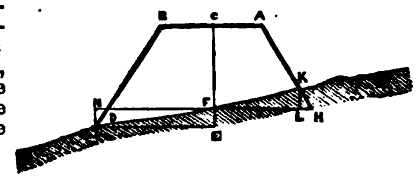
The natural tangent of 76° = 4·010781, hence the rise and fall of the slope of the surface of the ground at the cross-section may be taken as 4·01 to 1,

$$HF = \frac{28}{2} + \frac{2}{1} 20 = 54 = FD.$$

$4 \cdot 01 \times \frac{1}{2}$	=	2·005		$\frac{54}{1 \cdot 005}$	=	53·73
Subtract	..	1·000		Add	..	54·00 half-breadth.
		1·005		E M	=	107·73 ft.
Again, $4 \cdot 01 \times \frac{1}{2}$	=	2·005				54·00 half-breadth
Add	..	1·000		$\frac{54}{3 \cdot 005}$	=	17·97 take
		3·005		F L	=	36·03 ft.

In an embankment, Fig. 2669, given the breadth of the roadway A B = 30 ft.; the height C F = 12 ft.; the ratio of the side slopes 1 : $\frac{3}{4}$; the elevation or inclination of the surface of the ground in the direction of the cross-section = 3°, that is, angle K F H = D F M = 3°. Required the horizontal distances E M, F L, where the surface of the ground meets the side slopes. 90° − 3° = 87°; tan. 87° = 19·081137. Hence the rise and fall of the surface from the centre stake F may be represented by the ratio 19·08 to 1.

2669.



$$HF = \frac{30}{2} + \frac{4}{3} \times 12 = 31 = FD.$$

$19 \cdot 08 \times \frac{3}{4}$	=	14·31		$\frac{31}{13 \cdot 31}$	=	2·33
Subtract	..	1·00				31·00 = F D
		13·31				33·33 = E M.
Again, $19 \cdot 08 \times \frac{3}{4}$	=	14·31		$\frac{31}{15 \cdot 31}$	=	2·03
Add	..	1·00				31·00 = F H
		15·31		Difference		28·97 = F L.

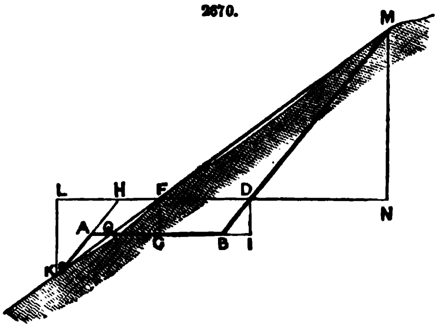
The simplicity of this plan of putting down side stakes is apparent, and the formula from which it is deduced is easily remembered.

$$HL = \frac{d}{ne+1};\ d = FH. \qquad DN = \frac{d}{nt-1};\ d = FD.$$

It should be remembered that in the ratio 1 to n, 1 represents the base, and n the perpendicular of the side slopes. In the ratio t to 1, t represents the base, and 1 the perpendicular rise in the case of a cutting, and *vice versâ* in the case of an embankment, see Figs. 2667, 2668. The ratio e to 1, e represents the base and 1 the perpendicular.

To set out the widths when the surface of the ground is laterally sloping, and when the cross-section consists partly of cutting and partly embanking. Let K, A, Q M B, Fig. 2670, be the cross-section of a railroad, consisting partly of a cutting Q M B, and partly of an embankment A Q K. Let l = A B = D H, the bottom width, F the centre stamp, F C = h the depth of the cutting, K M the sloping surface of the ground. First, suppose the embankment A K Q to occupy less than half the bottom width, as from A to Q, Fig. 2670. And further, suppose the ratio of the slope of the earth on both sides of the centre stake F to be represented by the same ratio t to 1; that is, F N : N M :: t : 1, or F L : L K :: t : 1. Yet the reasoning upon which the practical rule is founded will apply to two different slopes of ground, from the centre stake F, as in the former case. When the slope of the ground is known, or the ratio t : 1 is determined, then the point Q where the slope meets the base is readily found; for 1 : t :: F C : C Q. Or, Q C = $h\,t$. That is, if the height h multiplied by t be less than A C, half the breadth of the roadway, the work will be at the cross-section part cutting and part embanking

2670.



Let the side slopes be represented by the ratio 1 : n, that is,

$$BI : ID = DN : NM = HL : LK = 1 : n. \qquad \text{Put } DN = x, \text{ and } HL = y.$$

The horizontal half-breadth F D, through F, to meet the slope of the cutting, is found as in the former investigation, where the slope of the ground does not meet the roadway at either side of F.

$$FD = \frac{b}{2} + \frac{1}{n} \times h, \text{ which put} = d.$$

The horizontal half-breadth F H, through F, to meet the slope of the embankment K H, is easily found when F D is known, for

$$HD = AB = b, \text{ and } HF = HD - FD = b - \left(\frac{b}{2} + \frac{h}{n}\right) = \frac{b}{2} - \frac{h}{n},$$

which put = δ = H F.

$$1 : n :: x : nx = NM.$$

$$\text{Also,}\quad t : 1 :: d + x : \frac{d+x}{t} = NM; \qquad \therefore\ nx = \frac{d+x}{t}, \quad \text{or } x = \frac{d}{nt-1}.$$

This result is exactly the same as that given before, for the increase of horizontal breadth in the case of a rise in cutting, or a fall in embanking.

$$1 : n :: y : ny = KL.$$

$$\text{Again,}\quad t : 1 :: \delta + y : \frac{\delta + y}{t} = KL; \qquad \therefore\ ny = \frac{\delta + y}{t}, \quad \text{or } y = \frac{\delta}{nt-1},$$

which is a similar expression to that given for x; the only difference is that δ = H F is put in the place of d = F D.

Example.—Let A B = b = 28 ft.; F C = h = 4 ft.; the side slopes 1 : 2 (B I : I D :: 1 : 2); the cross-slope of the ground 13 to 1 (F N : N M :: 13 : 1). Required the horizontal distances F N and F L where the slopes meet the surface.

$$FD = \frac{28}{2} + \tfrac{1}{2} \text{ of } 4 = 16 = d. \qquad FH = 28 - 16 = 12 = \delta.$$

$$\text{Since}\quad n = 2, \text{ and } t = 13, \qquad \therefore\ \frac{16}{2 \times 13 - 1} = \cdot 64, \quad \text{and } \frac{12}{2 \times 13 - 1} = \cdot 48.$$

$$\therefore\ 16\cdot 64 = FN \qquad 12\cdot 48 = FL.$$

Example.—In Fig. 2671, the embankment M B Q occupies more than half the bottom width, as from B to Q. Let A C = C B = 14 ft.; F C = 4 ft.

$$FL : LK :: 13 : 1, \qquad HL : LK :: 1 : 2;$$

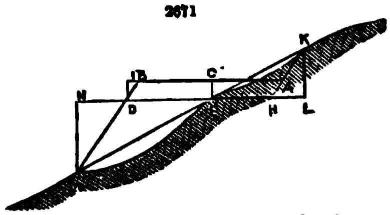
as in the last example, required the horizontal distances from F to L and from F to N.

$$FD = \frac{28}{2} + \tfrac{1}{2} \times 4 = 16 = d, \qquad FH = 28 - 16 = 12 = \delta.$$

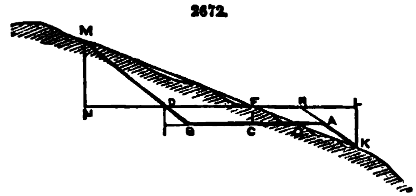
Since $n = 2$, and $t = 13$, $\therefore \dfrac{16}{2 \times 13 - 1} = \cdot 64$, and $\dfrac{12}{2 \times 13 - 1} = \cdot 48$;

Hence F N = 16·64, and F L = 12·48 ft.

2671



2672.



Example.—In Fig. 2672 the embankment A Q K occupies less than half the bottom width from Q to A. Let A C = C B = 14 ft.; F C = 4 ft.;

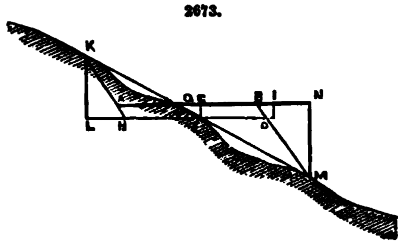
F L : L K :: 13 : 1; B I : I D :: 1 : 2.

Required the horizontal distances from F to L, and from F to N.

$$\text{F D} = \frac{28}{2} + \tfrac{1}{2} \times 4 = 16 = d; \qquad \text{F H} = 28 - 16 = 12 = \delta.$$

$$\therefore \frac{16}{2 \times 13 - 1} = \cdot 64, \quad \text{and } \frac{12}{2 \times 13 - 1} = \cdot 48, \qquad \text{F N} = 16 \cdot 64, \quad \text{and F L} = 12 \cdot 48 \text{ ft.}$$

2673.



Example.—In Fig. 2673 the embankment Q B M occupies more than half the bottom width, from Q to B. Let A C = C B = 14 ft.; F C = 4 ft.

F L : L K :: 13 : 1; H L : L K :: 1 : 2.

Required the horizontal distances from F to L and from F to N.

$$\text{F D}=\frac{28}{2}+\tfrac{1}{2}\times 4=16=d. \qquad \text{F H}=28-16=12=\delta.$$

$$\left.\begin{aligned} \text{D N} = x = \frac{d}{n\,t - 1} = \cdot 64 \\ \text{H L} = y = \frac{\delta}{n\,t - 1} = \cdot 48 \end{aligned}\right\} \text{ as in the foregoing examples.}$$

$$\text{F N} = 16 \cdot 64, \qquad \text{and F L} = 12 \cdot 48 \text{ ft.}$$

By comparing the Figs. 2670 to 2673, and observing how the formulas

$$x = \frac{d}{n\,t - 1} = \text{D N}, \qquad \text{and } y = \frac{\delta}{n\,t - 1} = \text{H L},$$

may be applied in every possible case, the setting out of side stakes, when part of the cross-section is a cutting and part an embankment, becomes easy

Works relating to this subject:—Macneill, 'Tables for the Calculation of Earthwork,' 8vo, 1846. F. Bashforth, 'General Table for the Calculation of Earthworks,' 8vo, 1855. D. Cuningham, 'Tables for the Calculation of Earthwork,' royal 8vo, 1867. Greenbank and Pigot, 'Metrical Earthwork Tables,' square 16mo, 1867. J. C. Trautwine, 'On Excavations and Embankments,' 8vo, 1868. G. P. Bidder, 'Earthwork Tables,' 18mo.

EMBOSSING. Fr., *Art de travailler en bosse;* Ger., *Bossiren;* Ital., *Imbozzare;* Span., *Realce.* [See Arming Press.]

EMBROIDERING MACHINE. Fr., *Machine à broder;* Ger., *Stickmaschine;* Ital., *Macchina da ricamare;* Span., *Máquina para bordar.* [See Sewing Machines.]

EMERY. Fr., *Émeri;* Ger., *Schmirgel;* Ital., *Smeriglio;* Span., *Esmeril.* [See Polishing and Grinding.]

ENGINE TURNING. Fr., *Travail au tour;* Ger., *Drechseln;* Ital., *Torno ad ornati geometrici;* Span., *Guillochis.* [See Lathes.]

ENGINES, VARIETIES OF. Fr., *Machines;* Ger., *Maschinen;* Ital., *Varieta di macchine;* Span., *Clases de máquinas.*

We have before stated that kindred articles, and those not complete in themselves, may be traced and combined by observing the references appended to such articles; thus, all that appertains to Steam and the Steam-Engine will be found under the articles headed Boilers, Details of Engines, Gearing, Indicators, Link-Motion, Locomotives, Marine Engines, Parallel Motions, Pumps and Pumping-Engines, Slide-Valves, Stationary Engines; and in the present article under the appellation, Engines, Varieties of. Steam-engines treated of in this place have peculiar mechanical combinations and arrangements, or they are employed to effect particular objects which require special notice.

The Corliss engine, in all except the cylinder with its valves and valve-gear, is substantially the same as any ordinary steam-engine; but it embodies in the arrangement of the cylinder and valve-gear several principles that had previously been used separately.

First, independent ports are used for admitting and for exhausting the steam at each end of the cylinder, with four separate slide-valves worked from a single eccentric.

Second, the steam is cut off from the cylinder by the main steam-valves, without the employment of any supplementary valves for the purpose.

Third, the steam-valves are opened against the resistance of springs, and a liberating gear is employed by which the valves are disconnected and left free to be closed by the springs.

Fourth, after the valves are closed, the springs are brought to rest without shock by the application of the contrivance known as the *dash-pot*, invented by F. E. Sickles. This consists of a small cylinder with closed bottom, in which a piston is fitted to work easily; and by a suitable arrangement of openings the air is admitted freely to the cylinder while the piston is moving, except when it approaches the bottom, at which time a certain amount of air is imprisoned, forming a cushion to prevent any shock when the piston actually reaches the bottom.

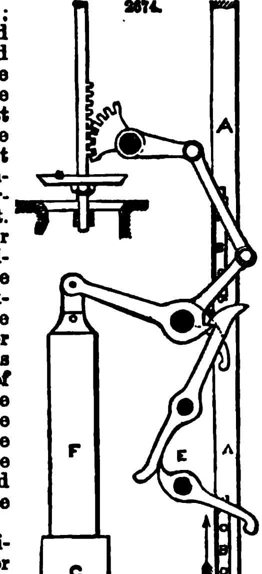
Fifth, the speed of the engine is regulated by the governor acting on the steam-valves to cut off the steam earlier, instead of acting on a throttle-valve to reduce the pressure of the steam.

It is the embodiment of these several principles, and the arrangement and construction of the details in the mechanism employed, rather than the application of any new or untried principle which constitute the special features of the Corliss valve-gear.

Cylinders with four separate passages and independent steam and exhaust slide-valves were used by Seaward previously, the valves employed being flat slides, but not worked in connection with any liberating gear; and a number of marine engines were made on this plan. In the earlier Corliss engines, Seaward's cylinders and slides were used; but the valve now employed is a cylindrical slide working in the arc of a circle on its seat, and receiving a rocking motion from a central valve-spindle. Although separate valves and passages were employed previously for steam and for exhaust at each end of the cylinder, the motion imparted to the steam-valves was invariable, and any expansion of the steam was effected by the lap of the valve. The speed of the engine also had to be controlled by throttling or shutting off the steam with a supplementary valve; and in this respect the first step in advance is made in the Corliss gear by the addition of the principle of liberating the steam-valve. With the employment of liberating gear it became necessary that an independent force should be available for closing the valves when they were detached, and for this purpose weights were first used; but springs have since been substituted for the weights, because they are quicker in action, effecting a sharper cut-off, and are better adapted for quick working. Liberating gear for the steam-valves was indeed used by Watt, so that the principle may be considered almost as old as the steam-engine itself; but in Watt's time it was more frequently for opening than for closing the valves that the weights used in that method of working were employed, and as might be expected the mechanism was not very perfect in its details. At that time the drop or poppet valve was used for the purpose.

To F. E. Sickles, of New York, is due the credit of perfecting the liberating gear as applied to the poppet or the double-beat valves, in the cut-off gear which bears his name. In this valve-gear, which was introduced in 1841 in America, the *dash-pot* is applied direct to the valve itself, to arrest the progress of the valve and prevent it from striking on its seat. It should be observed that there is an essential and important difference between the use of drop-valves and slide-valves, in connection with liberating valve-gear; for in the one case the dash-pot is applied to arrest the valve itself and prevent it from striking on its seat, but in the other it is only required to prevent the concussion of the weight or spring that is used to close the valve. If the drop-valve, in order to prevent concussion, is made to fall slowly just as it approaches its seat, it is evident that there must be a certain amount of wire-drawing of the steam; whereas with the slide-valve the motion of the spring or weight which closes it is not arrested by the dash-pot till after the valve is closed and the steam completely cut off; hence while the cut-off with the slide-valve must be perfect, with the drop-valve it must at best be to a certain extent imperfect.

2674.



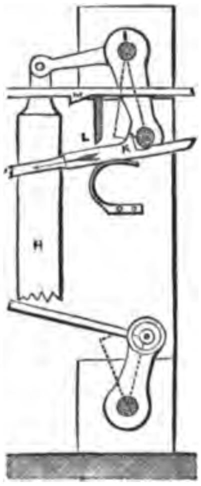
Regulating the speed of steam-engines by connecting the governor to vary the degree of expansion, instead of throttling the steam, was advocated, if not practised, by Watt, and many different arrangements have been invented and applied for effecting this object. In the Corliss expansion gear the governor is connected to the clips used to liberate the steam-valves, and according as the pressure of steam in the boiler or the load on the engine varies, the supply of steam to the cylinder is cut off at an earlier or later period of each stroke; so that the speed of the engine is kept uniform, without the addition of any throttle-valve in the steam-pipe. While the steam-valves are thus controlled by the governor, and caused to close at an earlier or later period of the stroke to suit the varying conditions of the steam-pressure or load on the engine, the exhaust-valves have an invariable motion, and are opened and closed at the same point of the stroke, whatever may be the degree of expansion.

The disconnecting valve-gear for working the steam-valves, as originally introduced by Watt and applied for the purpose of opening or closing poppet-valves, is shown in Fig. 2674. It was usual in this gear to communicate motion to the valves by a rod A called a plug-tree, attached to some moving part of the engine, generally to the beam; on this rod were fitted tappets B B, to open or close the valves when moving in one direction, and when moving in the opposite direction to trip or liberate the catches and allow the weights to act for either closing or opening the valves as might be arranged.

The drawing shows the plug-tree A with its tappets B B, the valve C, the catch D, and the curved lever E for tripping the catch, the weight F for closing the valve, and the dash-pot G for bringing the weight gradually to rest when dropped. All the details are rude and clumsy, but it can be seen that there is in this arrangement the germ, so to speak, of the Corliss expansion gear.

In Fig. 2675 is shown the arrangement of gear employed in the earlier Corliss engines in America for actuating the steam-valves; and the contrivance used for tripping or liberating the catch, in connection with a governor, to produce the sudden closing of the valves. In this arrangement a weight H was used, attached to a lever on the valve-spindle I, to supply the external force for closing the valve when the catch K was liberated, the weight falling in a dash-pot similar to that in Watt's gear. This plan was improved several years ago by Corliss, who then introduced an arrangement in which the catches push the valves open instead of pulling them, and the valves are closed by long blade-springs fitted to vibrating levers. The tripping of the catch is effected by curving up the back end at K, and this end when moving forwards comes into contact with a plate L, which is acted on by a rod M connected with the governor; the rod M carries an incline, which raises or lowers the plate L according to the changes in position of the governor balls, so that when the plate is lowered by the governor balls flying out in consequence of excess of speed, the catch K is tripped sooner, and reduces the supply of steam to the engine by cutting off the steam earlier. A few engines fitted with this arrangement of gear were made in this country some years ago, but the plan appears to have since fallen into disuse.

2675.



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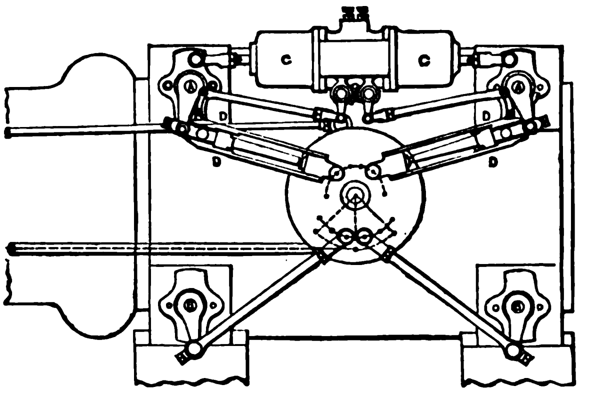
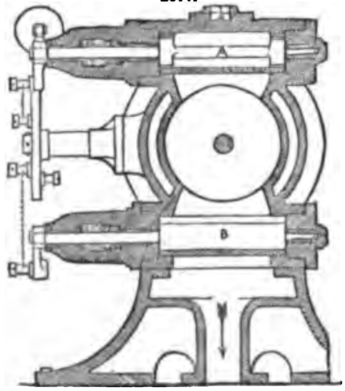
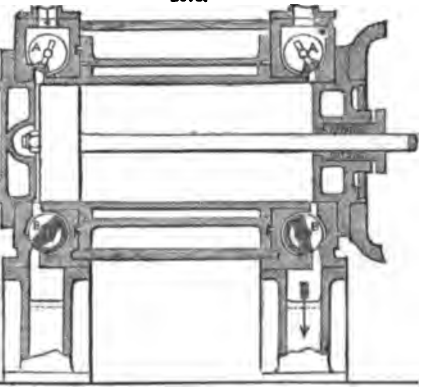


The present improved construction of the Corliss engine is shown in Fig. 2676, which is a side elevation of the cylinder and valve-gear of a small horizontal engine made by Hick Hargreaves and Co., of Bolton, for the Royal Arsenal at Woolwich, from designs by William Inglis. This engine, which has 12-in. cylinder and 2-ft. stroke, works at 100 revolutions per minute. The cylinder is shown in transverse section in Fig. 2677, and in longitudinal section in Fig. 2678. The

2677.



2678.



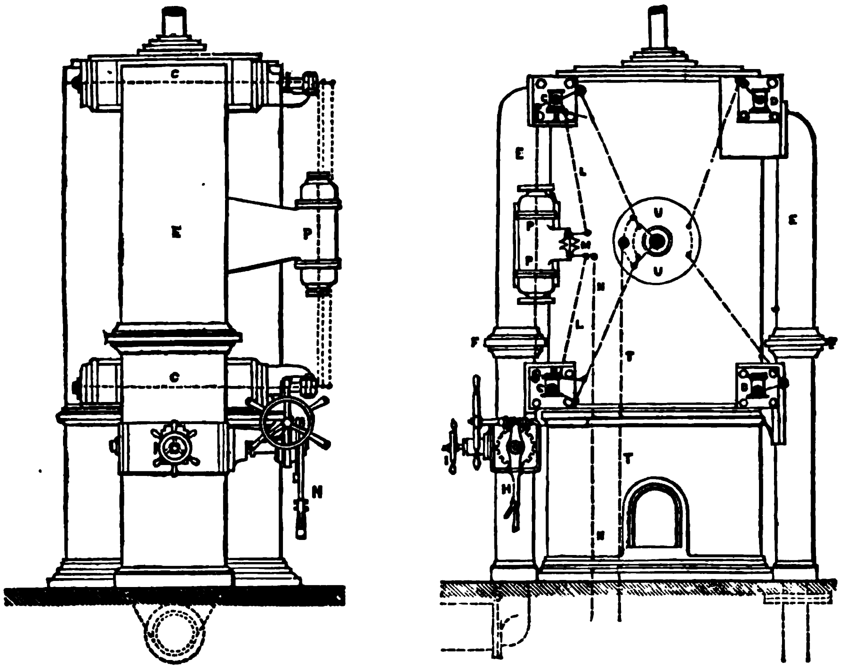
steam-valves A A are placed on the top of the cylinder, and the exhaust-valves B B at the bottom, separate pipes leading from them at each end of the cylinder. The steam-valves are closed by a spring dash-pot C C, which pulls upon each valve-rod as it is drawn out; and the liberating gear

consists of a pair of side spring-clips D D, which are released by the rocking of a double toe-lever E E, and then allow the steam-valve to be closed by the action of the spring: the spring-clips and toe-lever, and the valve-gear generally, are similar to those afterwards described in the Saltaire engines. The valves are cylindrical on the face, being similar in action to ordinary slide-valves, but working upon a cylindrical instead of a flat face; the valve face is a longitudinal segment of a cylinder, having recesses on its inner side, into which drop the projecting arms of the valve-spindle, so that the valve is moved by the partial rotation of the spindle in opposite directions alternately. The pressure of the steam on the valves tends to press them up to the face, only when the ports are closed; so that when the ports are opened, the valves move with practically no friction from the steam-pressure, and thus the pull required to close the steam-valves is small, and is practically independent of the pressure of the steam.

The cylinder is steam-jacketed both on the body and on the ends; and an improvement in the construction of these cylinders has recently been introduced by the writer, considerable trouble having been experienced in getting the jacketed cylinders sufficiently hard when cast in one piece, on account of the risk from cracking if cast with hard metal, and also in consequence of the annealing process that takes place during the cooling of the castings. The improvement consists in making the cylinder and valve-chest in four distinct pieces, with flanged face-joints F F to connect all together, as shown in Fig. 2678. The cylinder and the steam-jacket are two concentric castings, fitting one inside the other, with a flange F F upon the jacket only; and a separate casting at each end forms the valve-chests above and below the cylinder, with a ring connecting the two valve-chests; the end of the cylinder is fitted into this ring, and the cylinder cover is fixed upon it, all the fitting surfaces being turned and bored. The separate castings are thus rendered quite simple, and can be made of any degree of hardness without risk; while the flanged face-joints provide security against leakage, much better than if the inner cylinder were simply let in, with slip joints parallel to its bore. A saving of time in making can also be effected, as the work on the separate pieces can be proceeded with in several machines at the same time.

Figs. 2679, 2680, show a front and side elevation of one of the new cylinders with the improved Corliss expansion gear that have recently been erected at Saltaire by Hick Hargreaves and Co.,

2679 2680.



from designs by Wm. Inglis. The engines are beam-engines coupled together, with 50-in. cylinders and 7-ft. stroke, working at thirty revolutions per minute. There are two pairs of engines to be replaced, four cylinders in all, and the new cylinders have been put in place and now completed for one pair, and are the same size; the previous cylinders had double-beat valves actuated by a cam-motion. Figs. 2681 to 2683 are vertical and horizontal sections of one of the cylinders, showing the valves. The cylinders and cylinder covers are steam-jacketed; and the valve-chambers are cast with the cylinders. The steam-valves C C are in front and the exhaust-valves D D at the back of the cylinder, and the valve-gear is placed on the sides of the cylinders between each pair of engines. The steam and exhaust passages E E are cast separate from the cylinder, and provided with expansion joints F F, shown in section in Fig. 2681. The valves are cylindrical on the face, similar in construction to those of the Woolwich engine previously described. All the four valves are opened by the eccentric rod T, Fig 2680, acting on an oscillating disc U, to which the

four valves are connected by rods; the exhaust-valves D D are also closed by the same means, but the steam-valves C C are released, and are closed by an air-spring P. The stop-valve G in the steam passage is similar in make to the steam-valves, and is opened by a worm and worm-wheel to regulate the supply of steam; but it can be closed suddenly on any emergency by means of the

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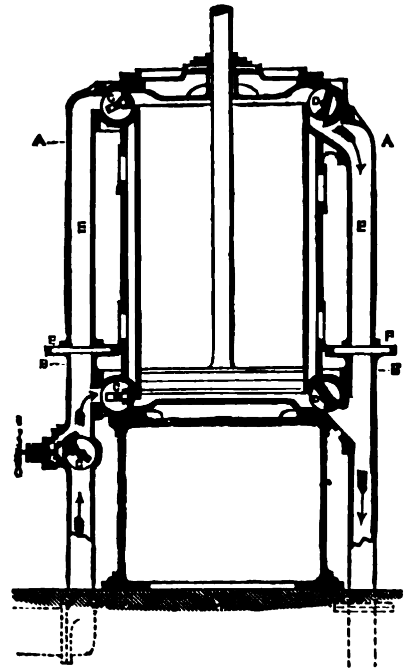

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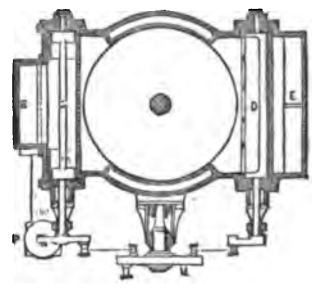
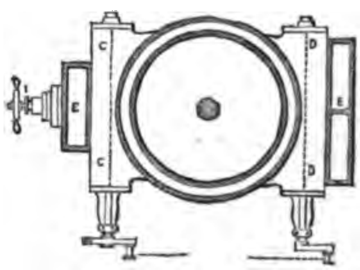


2683.



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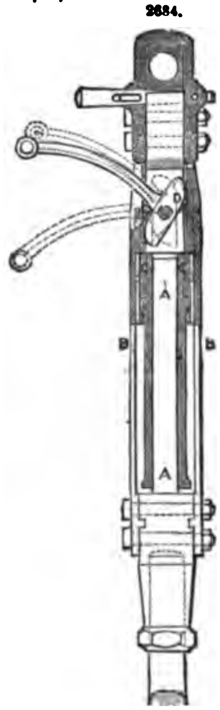

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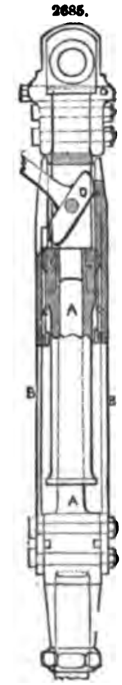

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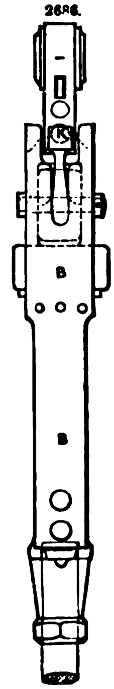


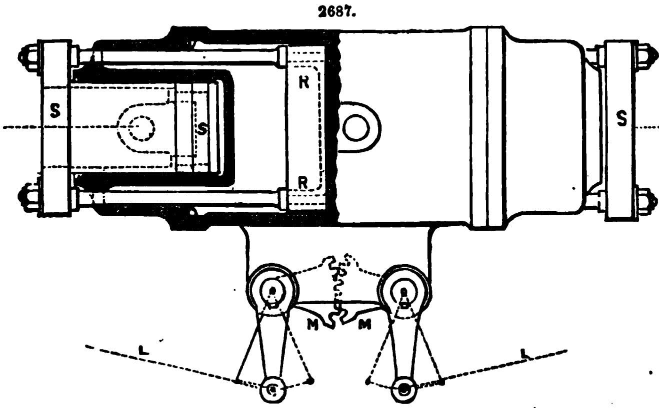
lever-handle H, which is keyed upon the valve-spindle, and is connected to the worm-wheel by a detent that can be instantly disengaged, the worm-wheel being loose upon the valve-spindle. A small auxiliary conical stop-valve I opened by a screw handle is employed for turning on the steam gradually at starting, to relieve the pressure on the main stop-valve G.

The construction of the liberating valve-rod introduced by Spencer and Inglis, for the disengaging gear to release the steam-valves, is shown in Figs. 2684 to 2686. The valve-rod is divided into two portions, one sliding steadily within the other at the cylindrical part A A; and the two are held together by the pair of spring-clips B B fixed on one portion, which rest on corresponding shoulders C C on the other portion of the valve-rod. The clips are released by the double toe-lever D, which rocks upon a transverse centre pin, and is shown in its two extreme positions in Figs. 2684, 2685; the outer end K of the arm of the toe-lever being held by the rod L, shown in the general drawing, Fig. 2680, the toe-lever D is made to rock in each stroke of the valve-rod, and the particular point of the stroke at which the toe-lever reaches its extreme position and disengages the spring-clips B B is determined by the position of the end K of the toe-lever arm, which is not stationary,

but is acted on direct by the governor through the rod L. By this means all changes in position of the governor balls produce corresponding changes at the same time in the position of the fulcrum upon which the toe-lever acts, causing the release of the spring-clips to be earlier or later in the stroke, according as the speed of the governor is greater or less than the correct rate, and thus regulating the engine by cutting off the steam earlier or later accordingly. The disengaging rods L L from the two steam-valves are coupled together by a pair of toothed segments M M, shown in Fig. 2680, and also in the enlarged drawing, Fig. 2687; and the rod N, Fig. 2680, connects these with the governor. The spring-clips B B fall upon leather faces O O, to prevent any blow in closing; and the engaging edges of the clips and the shoulders are hardened steel faces let in and readily renewable.

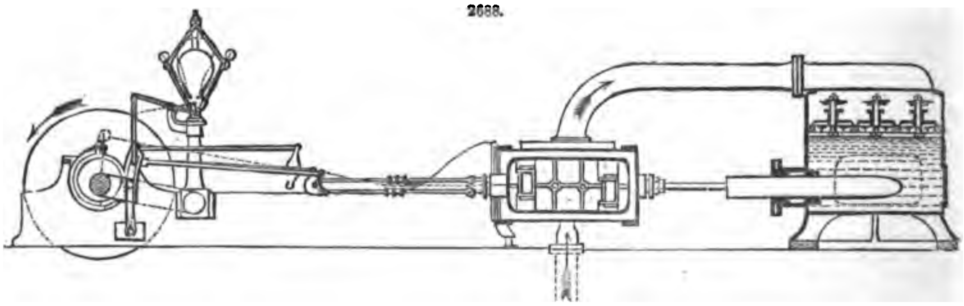
The air-spring dash-pot P for this gear, Fig. 2680, is shown enlarged in Fig. 2687, one half in section. It consists of two cylinders, one within the other; the large cylinder has a loose-fitting piston R R, and the small cylinder a trunk piston S S fitted with metallic packing; the under-side of this trunk piston is in connection with the condenser. The pressure of the atmosphere is therefore constantly pressing the small piston in, and this forms the spring for instantly closing the steam-valve when liberated from the clip-rod; the large piston R is coupled to the small one S, and acts as a dash-pot to prevent concussion in closing the steam-valve, as the air below th loose-fitting large piston R has to be driven out at the moment of closing the valve.

2687.

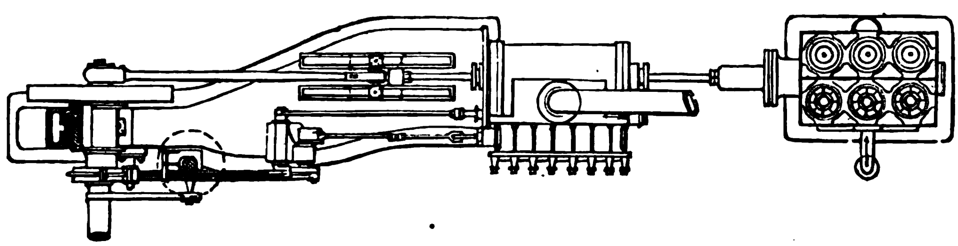


The Allen Engine and Governor.—C. Porter, in the Proceedings of I. M. E., justly observes that the principal objects to be aimed at in carrying out expansion in a steam-engine, so as to effect the greatest economy, may be stated to be;—that the full boiler-pressure should be carried into the cylinder at the commencement of the stroke, and maintained up to the point of cut-off;—that the cut-off should be sharp, without reduction of the steam-pressure by wire-drawing;—and that the exhaust should be invariable, allowing the steam-pressure to act to the end of the stroke with all degrees of expansion, and discharging the steam with the least loss from back pressure during the return stroke.

2688.



2689.



The attainment of these objects has generally been considered practicable only by means of some kind of liberating valve-gear, in which the valve is released from the gear when wide open, and is closed suddenly by a spring or by the action of gravity, so as to avoid the reduction of pressure by wire-drawing, which ordinarily takes place through the gradual closing of the steam-port by a slide-

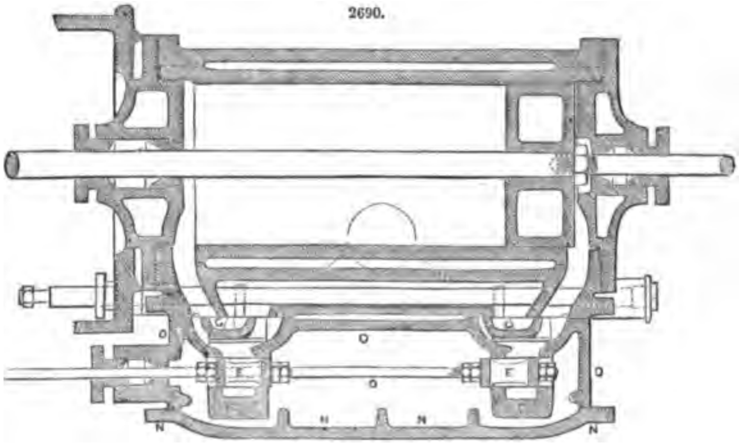
valve worked with a continuous motion. Many ingenious constructions of liberating valve-gear have been invented for effecting this object; and amongst them the Corliss engine, just described, has been found to accomplish the desired end very successfully.

In the Allen engine, however, the preceding requirements are met by a direct continuous action of the slide-valves, which gives a sharp cut-off to the steam admitted at full boiler-pressure, and a high range of expansion, together with a very free exhaust. At the same time this arrangement obviates the objection attending the principle of a liberating valve-gear, namely, that the speed at which the engine can be worked is limited by the circumstance of the valve having to be disconnected from the driving gear and connected again at each stroke of the engine. The Allen engine admits of being worked at a very high speed, much higher than is usual in stationary engines; and it maintains complete steadiness of motion at this high speed, combined with a great uniformity in the driving power throughout each revolution, although the steam is admitted at an unusually high pressure at the commencement of the stroke.

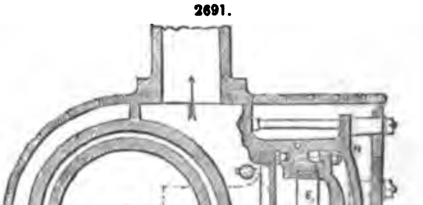
The engine is represented in Figs. 2688, 2689, which show a side elevation and plan of an engine with cylinder of 12 in. diameter and 24 in. stroke. This engine was employed at the works of the Whitworth Company, at a constant speed of 200 revolutions a minute, or 800 ft. a minute speed of piston, driving a considerable portion of the machinery in the works; and a similar engine was worked at the Paris Exhibition, running at the same speed. The engine is horizontal, fixed upon a bed-plate, and working an air-pump direct from the piston-rod, which is prolonged through the outer end of the cylinder. The slide-valves are worked by a link-motion, which is controlled entirely by the governor, giving a variable degree of expansion according to the amount of work to be done by the engine; but the steam is always admitted to the cylinder at full boiler-pressure, without passing through a throttle-valve.

Valves and Valve-Motion.—The steam slide-valves are shown in the longitudinal and transverse sections of the cylinder, Figs. 2690, 2691. The steam-valves are independent of the exhaust-

2690.



2691.

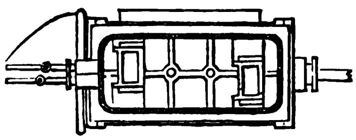


valves, and two separate valves are employed, one for each port. The two steam-valves E E are driven with separate motions, independent of each other, so as to effect a sharp cut-off at each end of the cylinder by the rapid motion of each valve at the point of closing the port; the motion of one valve being rapidly accelerated at the point of cut-off, at the same time that the other valve is greatly retarded. Each steam-valve consists merely of an open rectangular frame sliding between two parallel faces, which are fixed, so that the valve is in equilibrium and its motion is not affected by the pressure of the steam. The outer face F, against which the back of the valve slides, is a rigid plate bridging across the port and fixed down solid to the port face; and it is adjusted so as to allow the valve to slide freely, but with so good a fit as to be steam-tight. The travel of the valve in opening extends beyond the two faces, so as to admit the steam to the port at four places simultaneously, as shown in the separate diagrams, Figs. 2700, 2701, in which the length of the valve-rods and the distance between the valves are shortened for convenience in the diagram. In Fig. 2700 the steam is shut off from the nearer port; and in Fig. 2701 the farther steam-valve is shown at the point of opening the port, just previous to the commencement of the stroke, the crank being at that moment in the position shown by the dotted line.

In order to maintain the proper working of these valves, the back plate F, Figs. 2690, 2691, is

made very rigid, so as to prevent any yielding under the pressure of the steam; and the entire plate with its side supports being surrounded by the steam is consequently exposed to the same expansion as the slide-valves In order to provide the means of adjustment in case of any wear, a packing strip is inserted on each side between the back plate and its side supports; so that by reducing the thickness of these packing strips the two faces can be readily let together at any time to fit the slide-valve. The wear is found however to be so exceedingly slight, on account of the absence of pressure on the rubbing surfaces, that there is no probability of any adjustment being required oftener than once a year.

2692.



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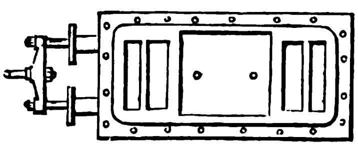

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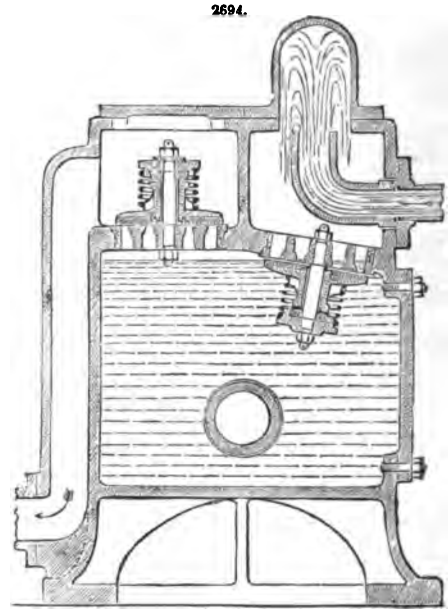

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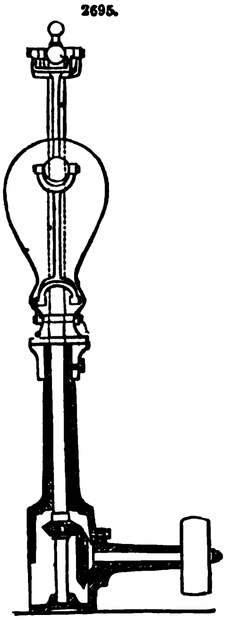

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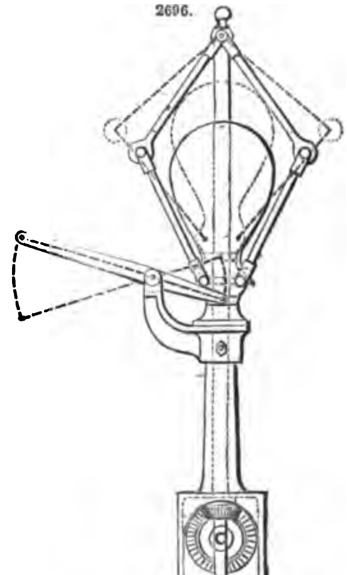

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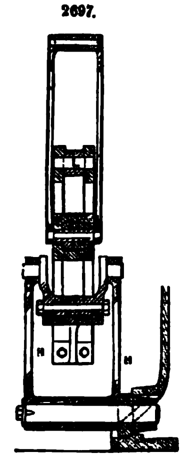
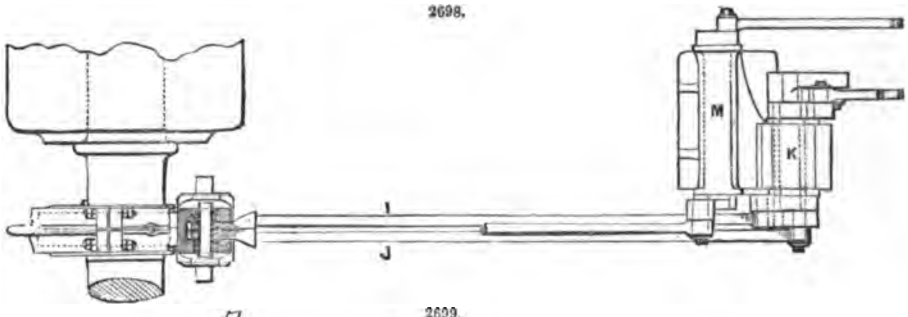


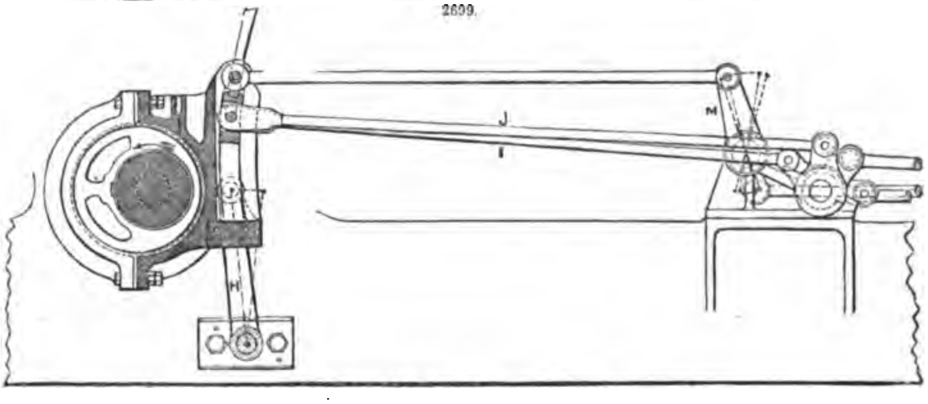
The exhaust-valves G G are also two separate valves, as shown in Figs. 2690, 2691, and in the diagram, Fig. 2702; but they move together and are driven by the same valve-rod. These slide-valves are of the ordinary form, and work in separate chambers, between the steam-valves and the cylinder; they travel beyond the port face, so as to open for the exhaust at the two edges simultaneously. As the steam-valves, however, open at four places simultaneously, the exhaust-valves

are made of nearly double the width, as shown in Figs. 2691 and 2693, in order to give a corresponding area of opening; and the extent of their motion is such as to give an area of opening for release of the steam more than double the largest area for admission. These valves work in equilibrium through most of their stroke.

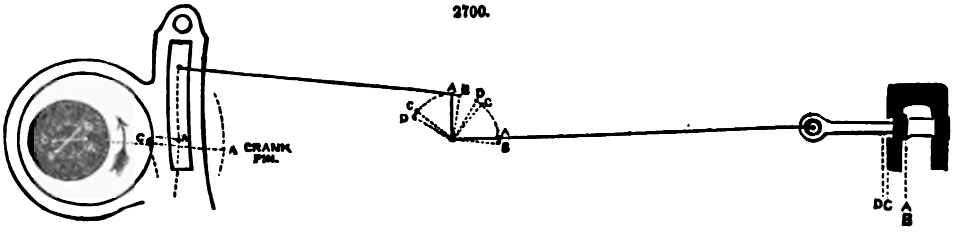
2698.



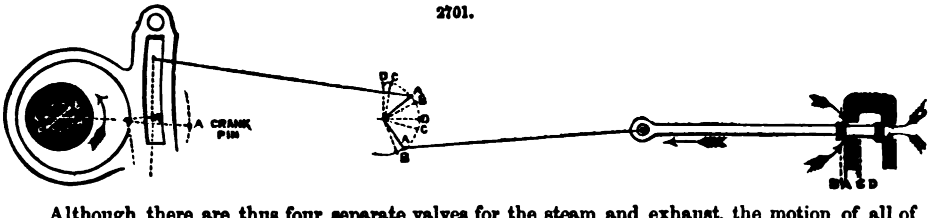
2699.



2700.



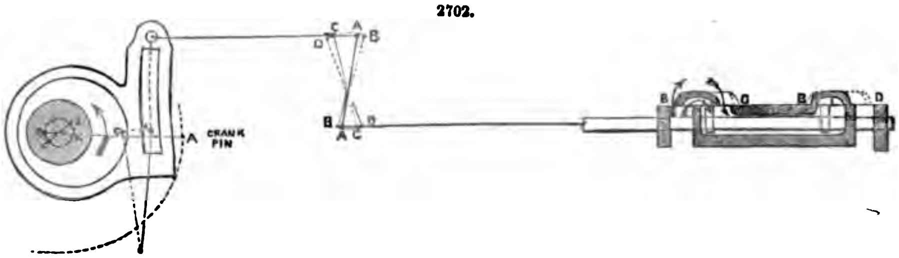
2701.



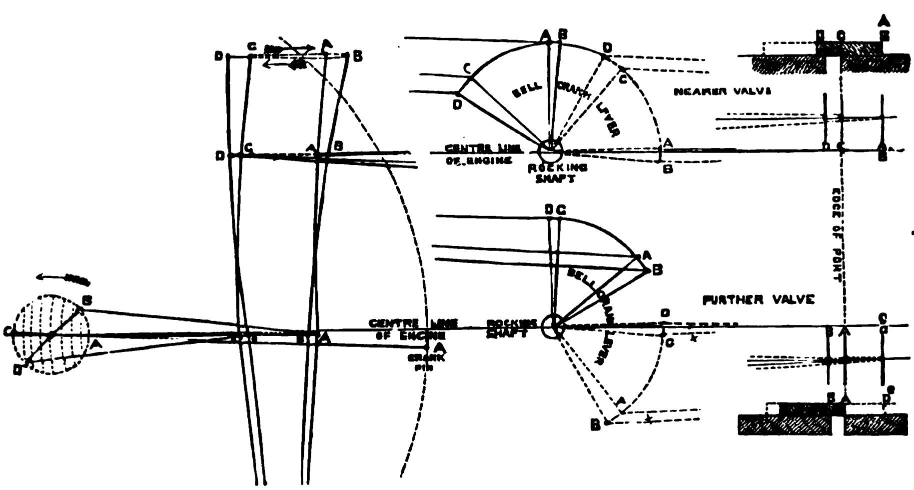
Although there are thus four separate valves for the steam and exhaust, the motion of all of them is obtained from a single eccentric, which is fixed on the crank-shaft in the same position as the crank, and without any lead, as shown in the diagram, Fig. 2703. The eccentric is shown in Figs. 2697 to 2699, and has a curved slot in one side of the strap, which acts as the expansion-link; and it is guided in its motion by being connected to the upper end of the vibrating lever H centred below. Two valve-rods, I and J, are connected to the same slide-block in the link, and attached at the other end to two separate bell-crank levers upon intermediate rocking shafts, as shown in the diagrams, Figs. 2700, 2701. One of these rocking shafts is made tubular, with the second running through it, as shown at K, in Figs. 2698, 2699, so that the two shafts work independently of each other. The second arms of the two bell-crank levers are connected respectively to the two steam-valves, Figs. 2700, 2701. The slide-block in the expansion-link is carried by two side links from the arm of the governor, as shown in Fig. 2688, so that its position is regulated entirely by the governor, the block being lowered so as to cut off the steam earlier whenever the governor balls begin to fly out in consequence of any increase of velocity.

The motion of the exhaust-valves is invariable, and they are connected direct to a point L, Figs. 2697 and 2699, beyond the outer end of the link-slot. A greater travel is thereby given to the exhaust-valves, as shown in Fig. 2702, than the greatest travel of the steam-valves; and this motion is continued the same during every change of expansion produced by shifting the slide-block from which the steam-valves are moved, so that the exhaust continues equally free with every degree of expansion. The point of connection to the link is so placed as to give the required lead to the exhaust-valves, and is arranged beforehand to suit the intended speed of piston. The exhaust-valves are driven through an intermediate rocking shaft M, Fig. 2699, for reversing the motion obtained from the eccentric; and a pair of valve-spindles are used, one at each edge of the two valves, as shown in Figs. 2691 and 2693, and working within the intermediate exhaust-port, Fig. 2690. The spindles are guided at each end, and each valve is connected to them by two studs fixed in the valve, which fit into slots in the spindles, working clear within the opening of the ports, Figs. 2690, 2691, and 2702. In the case of the steam-valves, as the two valves have independent motions, the spindle for driving the farther valve passes free through a short tube in the lower side of the nearer valve, Fig. 2691; the two spindles are made to clear each other by the valves being placed out of line with each other, as shown in the elevation of the steam-port faces, Fig. 2692; the spindles are kept central in each of the valves.

2702.



2703.



All the valves are readily accessible by simply removing the nuts of the steam-chest cover N, Figs. 2690, 2691, as the steam-chest is not cast solid upon the cylinder, but is a separate rectangular frame O O, fitted down with a scraped joint on both faces, and secured by the same through-bolts that fix the cover N. This construction has the important practical advantage that the steam-chest can be entirely removed, and all the port faces can be readily got at like plain outside surfaces.

In this valve-motion the proportion between the throw of the eccentric and the length of eccentric-rod, or the distance from the centre of the eccentric to the centre of the link, is made the same as the proportion between the main crank and the connecting-rod, which in this engine is 1 to 6, or the length of connecting-rod is three times the stroke. Consequently as the eccentric is set exactly to correspond in position with the crank, the angular vibration of the one compensates for that of the other, and an exactly correct valve-motion is obtained, giving the same results for each end of the cylinder. A considerable difference often exists in the indicator figures taken from the opposite ends of a cylinder, in consequence of the discrepancy between the motions of the connecting-rod and the eccentric-rod; and the difference in speed of piston during the first degree of rotation of the crank at the extreme opposite ends of the stroke amounts to 28 per cent. of the higher speed when the connecting-rod is six times the crank, 33 per cent. when five times, and 40 per cent. when four times the crank. In such cases, therefore, the point of cut-off is not the same in the two strokes

of the piston; but in the present engine the two strokes are identical throughout, in consequence of the eccentric and connecting rods having exactly parallel and simultaneous motions.

The connection of the expansion-link to the steam-valves by the intermediate bell-crank levers introduces in effect a toggle-joint movement, which has the important advantage of allowing the length of the valves to be reduced very considerably, because more than half of the lap or useless motion of the valves after having covered the ports is dispensed with by their motion being greatly retarded at that time; whilst the opening for steam admission is correspondingly increased by the motion of the valves being accelerated at the opposite extremity of their travel. This variation in the motion is shown by the diagram of the link-motion in Fig. 2703, and also in Figs. 2700, 2701, together with the varying angular motion of the bell-crank levers on the rocking shaft, the reference letters indicating corresponding positions throughout. The result is seen to be a very great range or variation in the motion of the valves, giving on the one hand a wider steam opening and a sharp cut-off with high degrees of expansion, and on the other hand a very slow motion of the valve during the time that it is simply retaining the port closed. The whole action is obtained with a continuous and perfectly smooth motion throughout.

In the adjustment of the centres of the link-motion, the centre of the supporting lever H, Fig. 2699, is slightly lowered, so that its upper end vibrates entirely below the centre line, as shown in Fig. 2703, in order thereby to equalize the extent of tipping of the link at the two extremities of its vibration. This gives a slightly increased lead to the steam-valve opening at the farther end of the cylinder, where the motion of the piston is the more rapid on account of the smaller arc of rotation of the crank; but the point of cut-off of the valves is exactly the same at the opposite ends of the cylinder for each degree of expansion, and the point of cut-off can be varied from $\frac{4}{10}$ of the stroke to the very commencement of the stroke.

For the purpose of obtaining the full benefit of expansion, it is requisite, in addition to having the full boiler-pressure in the cylinder and providing a sharp cut-off, that superheated steam should be used, in order not only to prevent water from being carried over into the cylinder with the steam, but also to prevent any loss arising from the freshly admitted steam becoming condensed in the cylinder by contact with the cylinder surface which has been cooled in the previous expansion. About 50° Fahr. of superheating is found desirable; and this proves a more efficient mode than steam-jacketing, because the superheated steam on admission into the cylinder supplies heat to the very surfaces that have been cooled by exposure to the low-pressure expanded steam.

Speed of Piston.—One of the objects aimed at in this engine is to work at speeds considerably higher than those ordinarily used in any but locomotive engines. For the following reasons it is considered that the speed of piston should not be less than 600 ft. per minute; but these engines have been worked continuously at the higher speed of 800 ft. per minute with complete success, and it is believed that still higher speeds may in some cases be employed with advantage. The valves and the whole of the working parts are so well adapted to maintain a high speed, that the practical objections which ordinarily limit the speed of piston to lower rates do not apply in the case of the present engine.

The principal object in adopting the high speed of piston is to obtain a sufficient reciprocating force in the moving parts for balancing the initial force of the steam upon the piston when admitted at full boiler-pressure at the commencement of the stroke, so as to relieve the crank from strain on passing the centres; and also to equalize more fully the driving force upon the crank during the entire stroke. At the commencement of each stroke, an accelerating force is required sufficient to put in motion the mass of the reciprocating parts at the velocity at which the piston moves from a state of rest; and the speed of piston is adjusted so as to make this required force as great as the actual full force of the steam upon the piston when admitted at the boiler-pressure, so that the two forces are in equilibrium at that point and the crank-pin is thereby relieved from strain when passing the centre. This accelerating force imparted to the piston at the commencement of the stroke is given out again during the retardation of the piston in the latter half of the stroke, and thus compensates for the diminishing driving force of the expanding steam, and acts to equalize the driving power upon the crank. A similar action takes place in all engines, but at the speeds of piston ordinarily employed its extent is too small to produce any material effect; and it is only with a high speed that the effect becomes important, since the force required to put in motion or to stop the reciprocating parts increases as the square of their velocity of motion. Where a high speed is combined, as in this engine, with an unusual weight of the reciprocating parts and a short stroke, the inertia of these parts acts as a powerful reciprocating fly-wheel to equalize the driving power of the engine throughout the revolution of the crank.

In the present engine the weight of the reciprocating parts is 470 lbs., the cylinder 12 in. diameter by 24 in. stroke, and the number of revolutions 200 per minute, or one revolution in 0·3 second. Taking the motion of the piston in the first degree of revolution of the crank at the commencement of the stroke, the extent of motion will be the versed-sine of an angle of 1° with a radius of 1 ft., or 0·000152 ft. in the time of $\frac{1}{360}$ of 0·3 second, or $\frac{1}{1200}$ second; which is equivalent, as regards the accelerating force required to produce it, to a motion of 219 ft. in one second, the space passed through under a uniform accelerating force being in proportion to the square of the time. This motion of 219 ft. in one second is 13·7 times the effect of gravity (16·08 ft. in one second); and consequently the force required to impart the velocity amounts to 13·7 times the weight of the reciprocating parts (470 lbs.), making a total force of 6439 lbs., which is equal to a pressure of 57 lbs. per square inch upon the area of the 12-in. piston. It follows, therefore, that the steam at the full pressure of 57 lbs. may be admitted suddenly to the cylinder at the commencement of the stroke, without causing any strain upon the crank-pin; and indeed this full pressure is absolutely required upon the piston at that moment, in order to prevent a strain in the opposite direction upon the crank-pin from the inertia of the reciprocating parts.

For carrying out a high degree of expansion a high speed of piston is essentially requisite, in order that a sufficient amount of equalizing effect may be obtained from the inertia of the re-

ciprocating parts, to compensate for the extreme variation in steam-pressure which is consequent upon an early cut-off. Indeed, in consideration of smoothness of running, the engine should be run so fast that the driving force produced by the highest pressure of steam cannot exceed the inertia of the reciprocating parts; and then a knock upon the centres becomes as impossible as it would be in a revolving sling.

A high speed of piston is also advantageous on account of the reduction in size of engine required to supply a given amount of power, whereby an important saving in space and cost is effected; and also on account of the increased uniformity of motion obtained with the higher speed. Taking the case of a single engine in place of a pair of coupled engines running at half the speed, the strokes are as frequent as those of the pair of engines, while the inequalities in the rotative force are not much larger, owing to the great equalizing effects of the inertia of the reciprocating parts at the high speed. Moreover, as the regulating power of the fly-wheel increases in proportion to the square of the number of revolutions in a given time, the same wheel has four times the regulating power when run at double the speed.

The practical objections generally considered to apply to a high speed of working are, increased wear and tear, risk of hot bearings, cutting of the cylinders and pistons, and shaking loose in the fixings. But instead of any difficulties of this kind having been experienced, this engine runs smoothly and quietly, without tremor and without warming in the bearings, running continuously without requiring attention, and showing exceedingly slight wear in the cylinders, valves, and bearings. This result has been attained simply by good mechanical construction and workmanship; avoiding any unbalanced action, overhanging strains, insufficient stiffness of framing, inadequate bearing surface, or want of truth in workmanship. Unless all these conditions are carefully attended to, high speed is certainly not practicable; but when they are thoroughly carried out, no difficulty is experienced in working at any desired speed.

In the previous consideration of the effect produced by the inertia of the reciprocating parts, this has been taken as the same at each end of the stroke; but in reality a considerable difference is caused by the angular motion of the connecting-rod at the two ends of the stroke; and the actual motion of the piston during the first degree of rotation of the crank, instead of being 0·000152 ft. at each end, is 0·000178 at the outer end of the stroke, and only 0·000127 at the inner end. Consequently, from this approximate mode of calculating by the difference in motion of the piston during the first degree of rotation from each end of the stroke, the pressure on the piston required to balance the inertia, instead of being 57 lbs. an inch at both ends, as named before, would be 66 lbs. at the outer end and 47½ lbs. at the inner end. In the case of inverted vertical engines, the weight of the reciprocating parts acting vertically tends to equalize these amounts, by being added at the outer or upper end and deducted at the lower end. For this reason, and on account of the more correct support of the cylinder and the absence of overhanging strains, that form of engine seems preferable for the highest speeds.

Condenser and Air-Pump.—In the arrangement of the condenser and air-pump the object has been to meet the difficulty of combining the advantage of a simple direct-acting air-pump with the very unusually high speed of working, 200 revolutions per minute. This has been effected with complete success by the construction adopted; a vacuum of 27 in. of mercury is maintained with great steadiness, and the air-pump works quite quietly and without noise at the full speed, and keeps thoroughly in order without requiring any attention.

The air-pump, as shown in Figs. 2688, 2689, and in the transverse section, Fig. 2694, is a nearly cubical box filled with water, with a plunger working through a stuffing-box in the lower part; the plunger is attached to the piston-rod and forms a continuation of it. The end of the plunger is made of a parabolic shape, as shown in Fig. 2688, for displacing the water easily; and the plunger works entirely immersed in the water, simply displacing its own bulk of water at each stroke.

The inlet and outlet valves are all placed in the top plate of the box in two parallel rows, three inlet-valves in one row and three outlet-valves in the other, as shown in the plan, Fig. 2689. They are india-rubber disc-valves with 8 in. diameter of opening, Fig. 2694, and slide parallel upon their centre spindles without any bending of the india-rubber, being fitted with a metal plate and a long centre bush to guide the discs steadily in opening and closing, and to prevent any wear upon the edge of the india-rubber. The lift of the valves is about ½ in.; and in order to obtain a quick action in closing they are closed by spiral springs, which load the valves to the extent of ¼ lb. per square inch. These springs are found necessary upon the outlet-valves as well as the inlet, in consequence of the quickness of the action required to close them 200 times per minute; and it was found that even at the speed of 120 times per minute there was a loss of 1 lb. per inch in the vacuum when the springs were not used, from the valves not closing promptly enough.

The condenser forms one half of the chamber above the air-pump, and the hot-well the other half, as shown in Fig. 2694. The injection is introduced by a single opening in the centre of the condenser, with the full area of the pipe, in order to avoid any risk of the injection-opening getting contracted by accumulation of deposit in a spreader or rose; and it has been found that no perceptible difference is caused by this arrangement in the vacuum obtained with the injection. In consequence of the position of the valves in the top plate of the air-pump chamber, the air entering from the condenser does not pass through the water, but simply passes over the surface of the water from the inlet to the outlet valves: and the water rising up to the outlet-valves at each stroke ensures the discharge of the whole of the air. As no air gets to the lower portion of the air-pump chamber, the plunger works always in solid water, avoiding any churning action of mixed water and air; and indeed the effective piston of the air-pump may be considered to be, not the plunger, but the surface of the body of water that always remains in the air-pump chamber, which rises and falls at each stroke of the pump through a distance of less than 1 in. The working velocity of the air-pump piston is therefore reduced in effect to only about 30 ft. per minute, instead of 800 ft. per minute, the actual velocity of the plunger.

For the purpose of facilitating the passage of the air from the inlet to the outlet valves, the former are set at a small inclination below the horizontal position, as shown in Fig. 2694. The arrangement and position of this condenser and air-pump are very convenient for access to all the parts, the whole being above ground and at the level of the engine. It is held steady in its position by a connecting-tie to the frame below and by the fixing of the exhaust-pipe above; and it serves as an additional guide for the smooth working of the piston-rod beyond the cylinder. The weight of the plunger moving at the full velocity of the piston serves also as an important addition to the compensating action of the inertia at the commencement and end of each stroke.

Governor.—The expansion-gear of the engine is regulated entirely by the self-acting movement of the governor, Figs. 2688, 2689; and for carrying this plan out satisfactorily it is essential to have a governor that is extremely sensitive to any change of velocity, and acts with great promptness upon the expansion-gear, with power sufficient to shift it instantly to the full extent required. The governor used for the purpose has been designed by the writer as a modification of the ordinary Watt centrifugal governor, with the view of increasing its sensitiveness and quickness of action, and adding to the power available for overcoming the resistance of the valve-motion. This resistance is, however, reduced to a very small amount in the present engine, on account of the valves being in equilibrium.

The governor is shown in Figs. 2695, 2696, and consists of two revolving balls of small size, but moving at a high velocity, which pull up a heavy central weight when they rise in consequence of an increased velocity of revolution: the balls are only about 2 to 3 lbs. weight, but the central weight is from 50 to 300 lbs., according to the size of the governor. The connection of the radius rods to the centre spindle is made with forked ends, having considerable width of fork, as shown in Fig. 2695, and fitting upon a pin which passes through the axis of rotation, Fig. 2696. The friction which opposes the rise and fall of the balls is thus reduced, by the pressure upon the pin at the joints of the rods being diminished in consequence of their increased leverage; and the sensitiveness of the governor is thereby increased, its friction being much less than that of the ordinary governor.

With the very heavy revolving balls employed in the ordinary construction of governor, a large amount of resistance is opposed by their inertia when they are required to act, by rising or falling, on the occurrence of a change in the velocity of revolution. A serious pressure is also caused on the joints of the radius rods when the inertia of heavy balls of 1 cwt. each has to be overcome in order to accelerate their motion; and the friction caused by this pressure on the joints prevents the change of position of the balls until a sufficient increase of velocity has occurred to accumulate force enough for overcoming this resistance. The engine is thus allowed to vary considerably in speed; and the balls of the governor are then liable to fly out too far, causing too great an action for properly regulating the speed of the engine. In the present governor the revolving balls, being of very small weight, offer little resistance by their inertia to any change, and they rise or fall instantly when any change takes place in the speed of revolution of the engine. Their centrifugal force is made up to that of the ordinary heavy balls by their increased velocity of revolution, the centrifugal force increasing as the square of the velocity; and they are driven at a speed of from 320 to 400 revolutions per minute.

This governor is liable to the same objection in principle as the ordinary Watt centrifugal governor, namely, that it can only regulate the engine for a variation of load by maintaining a corresponding change of velocity in the engine; but in this governor the action is so much more sensitive and extended than in the ordinary governor, that this objection is practically got rid of. It is found to regulate the speed of the engine with certainty within the range of 2 per cent. variation of speed, with the greatest extent of variation that can occur in the load; and a variation in speed of 5 per cent. would carry the governor through its entire range of action, and shut off the steam from the engine. In practice the steam stop-valve is always set wide open, and the engine runs under all circumstances with complete steadiness and uniformity of motion, without requiring any attention; and the most sudden and extreme changes of load do not affect its motion perceptibly.

Special Construction.—In practically carrying out the high speed of working that has been adopted in this engine, special attention has been required to ensure the rigidity of both the stationary and the moving parts, to balance the forces of the moving parts, and to obtain a large extent of hardened rubbing surface, with perfect truth of form in the wearing parts. When due attention is paid to these points, it is found that there is no practical difficulty attending the employment of the high speed; and the objections ordinarily felt to it arise really from imperfections of construction in these respects.

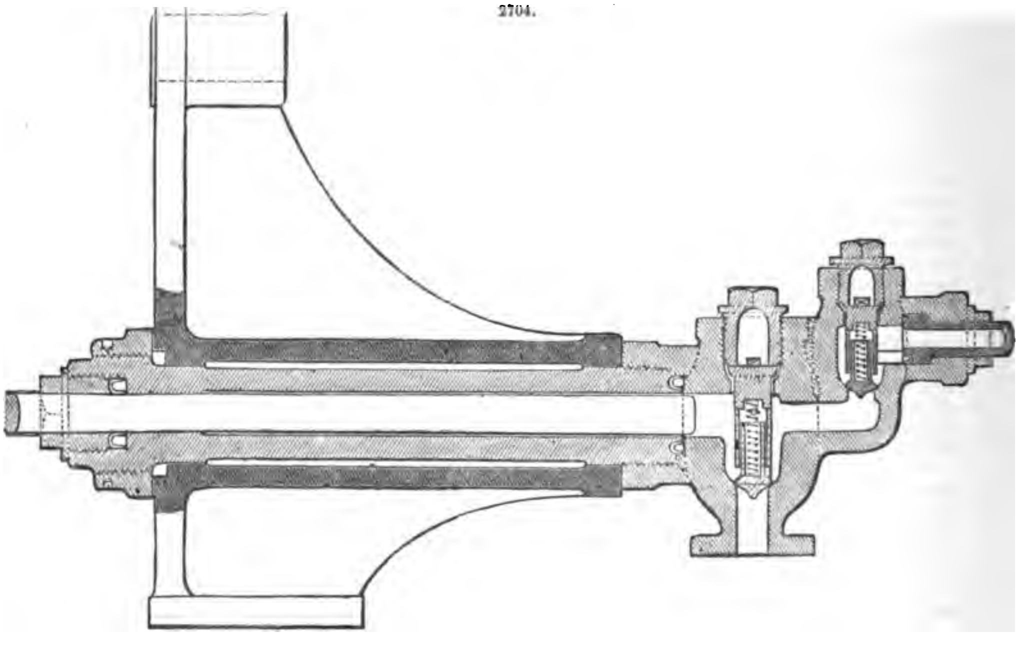
For the purpose of obtaining the required rigidity in this engine, the base-plate is made a hollow casting of great stiffness and unusual depth, and the centre line of strain of the engine is brought down very near to its surface. The cylinder is bolted to the end of the base-plate, and is held all round the circumference of its inner end; but it is left free from the base-plate throughout its entire length. The object of this arrangement is to leave the cylinder free to expand and contract, without the tendency to distortion which arises when the cylinder is fixed down throughout one side to a cold base-plate, whilst kept heated along the other side by the steam-chest. The cylinder thus preserves its parallelism when at work, so that a deep and well-fitted piston can be used; the piston employed is a plain hollow block, turned a close fit to the cylinder, and fitted with two Ramsbottom rings. The result is that, instead of the injurious wear often experienced in horizontal cylinders working at the lower speeds, the cylinders of these engines are found to be always in a polished and greasy condition, and their wear is inappreciable.

In all the working parts of the engine the bearings are made both unusually long and large in diameter, and by this means the pressure per square inch on the bearing surfaces is diminished, so that a thicker film of oil is maintained between them, reducing the coefficient of friction. The smoothness of running is thus increased also, by avoiding the injurious effects that arise from the

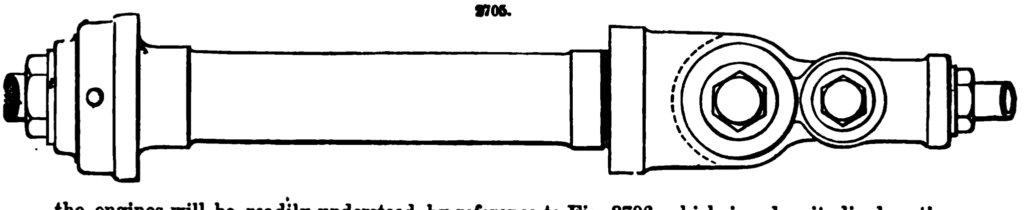
bearings not having sufficient rigidity to resist flexure or torsion. In all the bearings special care is taken to obtain perfect truth of form, which is a point of great practical importance; and if properly formed and hardened, these bearings should not be subjected to wear at all. The difference in working is remarkable between a true cylindrical form and such an approximation to it as can be produced by turning in a good lathe. When a truly cylindrical journal or pin has been produced by the operation of grinding with a traversing wheel, in dead centres which have themselves been ground to true cones, such a cylinder, if it has sufficient surface and rigidity, and is fitted in proper bearings, floats in an oil bath, being separated from the bearings at every point by a film of oil of exactly uniform thickness: this film cannot anywhere be broken, and having scarcely any disposition to work out, will last without renewal for a great length of time; and the coefficient of friction under pressure is thereby greatly diminished. This truth of form is really easy of attainment, and if its value were fully appreciated, it would certainly be obtained in general practice.

R. Wilson's Direct-acting Engine.—This engine is specially designed for the purpose of supplying water under a high pressure to hydraulic machinery, and has been extensively applied to the working of cotton presses. It is usually made in pairs (to secure a uniform delivery of water), each pair consisting of two steam-cylinders and four pumps coupled together, as shown in Figs. 2704, 2705, which represent two views of a complete pair of engines. The arrangement and action of

2704.



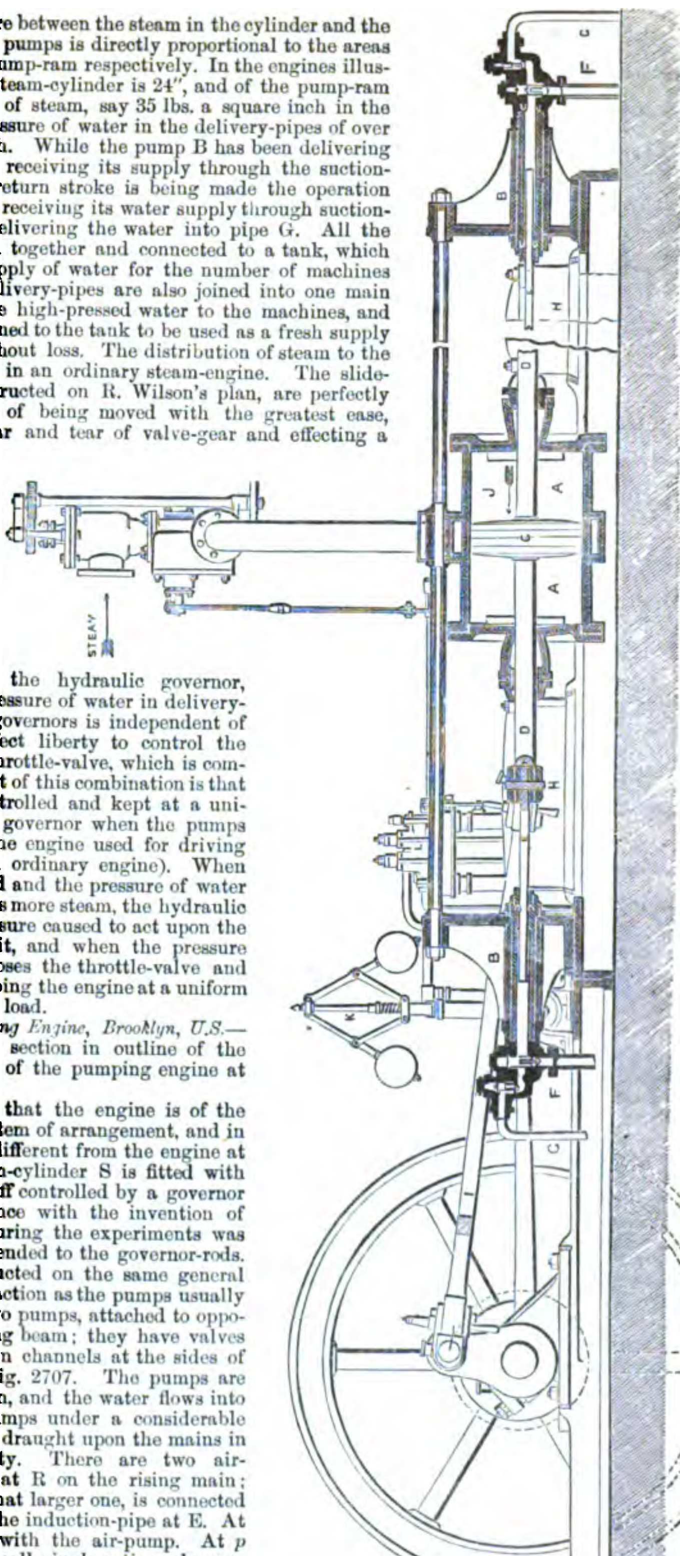
2705.



the engines will be readily understood by reference to Fig. 2706, which is a longitudinal section through one engine, or say one steam-cylinder and two pumps. A is the steam-cylinder; B B' the pumps; C, steam-piston; D, piston-rod extending through both ends of cylinder; E E' are pump-rams attached directly to the piston-rod, one at each end; F F' the suction, and G G the delivery pipes, each with their respective valves. At the junction of the pump-rams with the piston-rod at each end is a cross-head with a pair of slide-blocks working in slides H H. To the cross-head H is attached one end of a forked connecting-rod I, the other end of which is connected to the crank and crank-shaft with fly-wheel, as in an ordinary steam-engine. The other steam-cylinder and pair of pumps are attached to the same crank-shaft at right angles to those already described, by this means ensuring the pumps to be alternately brought into action, and therefore—the pumps being all connected to one delivery-pipe—secures a continuous uniform discharge of water.

It will be seen that if steam be admitted into the steam-cylinder at the right-hand end J, the piston will be pushed forward in the direction of the arrow by the full force of the steam, and the water contained in pump B is expelled by the pump-ram E, and passing over the suction-valve, which it keeps down, finds an outlet through the delivery-valve into the pipe G, at a high pressure.

The difference in pressure between the steam in the cylinder and the water passing out of the pumps is directly proportional to the areas of steam-cylinder and pump-ram respectively. In the engines illustrated the diameter of steam-cylinder is 24", and of the pump-ram $1\frac{11}{16}$", so that a pressure of steam, say 35 lbs. a square inch in the cylinder, will give a pressure of water in the delivery-pipes of over 3 tons to the square inch. While the pump B has been delivering its water, B' has been receiving its supply through the suction-pipe F, and when the return stroke is being made the operation is reversed, the pump B receiving its water supply through suction-pipe F, and pump B delivering the water into pipe G. All the suction-pipes are joined together and connected to a tank, which contains a sufficient supply of water for the number of machines to be worked. The delivery-pipes are also joined into one main pipe, which conveys the high-pressed water to the machines, and after being used is returned to the tank to be used as a fresh supply over and over again without loss. The distribution of steam to the cylinders is effected as in an ordinary steam-engine. The slide-valves, which are constructed on R. Wilson's plan, are perfectly balanced, and capable of being moved with the greatest ease, avoiding the usual wear and tear of valve-gear and effecting a great saving in the consumption of fuel. The valves are worked by means of eccentrics on the crank-shaft. The engine is fitted with two governors; the one marked K is of the ordinary ball construction, and the other, L, termed the hydraulic governor, is acted upon by the pressure of water in delivery-pipes. Each of these governors is independent of the other, and at perfect liberty to control the engine, by means of a throttle-valve, which is common to both. The object of this combination is that the engine may be controlled and kept at a uniform speed by the ball governor when the pumps are disconnected, and the engine used for driving other machinery (as an ordinary engine). When the pumps are connected and the pressure of water rises, the engine requires more steam, the hydraulic governor is by that pressure caused to act upon the throttle-valve to open it, and when the pressure lowers, the governor closes the throttle-valve and gives less steam, so keeping the engine at a uniform speed under its varying load.



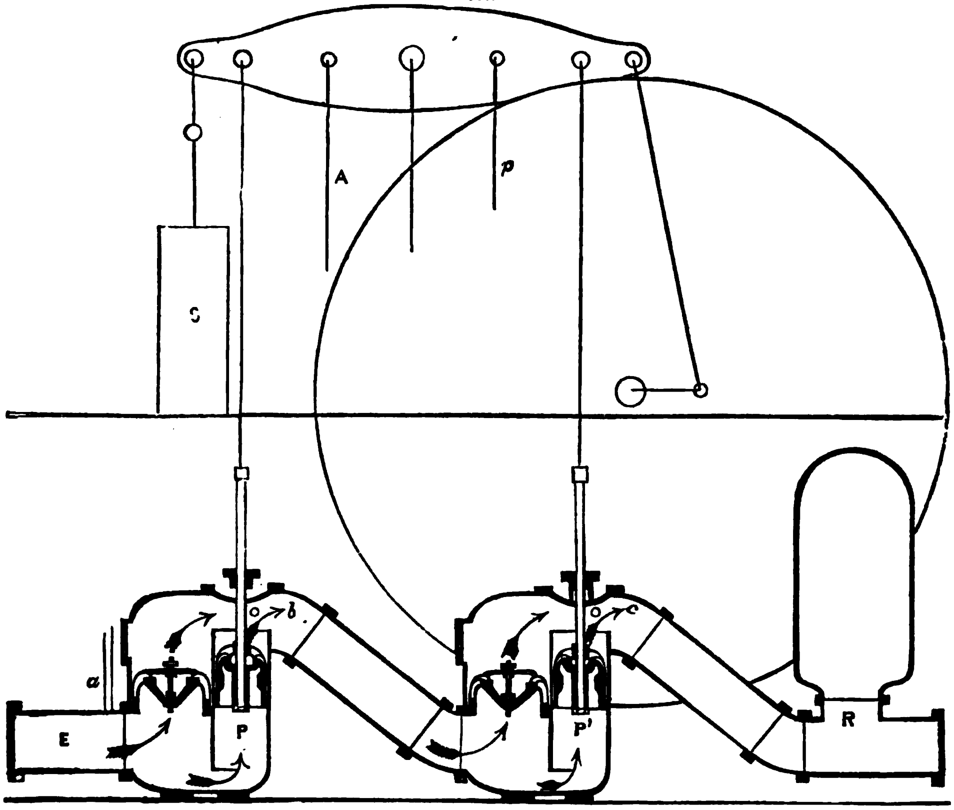
2706.

Prospect Hill Pumping Engine, Brooklyn, U.S.—Fig. 2707 represents a section in outline of the pumps and an elevation of the pumping engine at Prospect Hill.

It will be observed that the engine is of the crank and fly-wheel system of arrangement, and in this respect is entirely different from the engine at Ridgewood. The steam-cylinder S is fitted with slide-valves, and a cut-off controlled by a governor constructed in accordance with the invention of Wright. The speed during the experiments was varied by weights suspended to the governor-rods. The pumps are constructed on the same general principles and mode of action as the pumps usually employed. They are two pumps, attached to opposite sides of the working beam; they have valves in their buckets, and in channels at the sides of the pump, shown in Fig. 2707. The pumps are placed in a branch main, and the water flows into and through the air-pumps under a considerable head, variable with the draught upon the mains in other parts of the city. There are two air-chambers: one shown at R on the rising main; the other, and a somewhat larger one, is connected by a branch pipe with the induction-pipe at E. At A are the connections with the air-pump. At p the connections of a small single-acting plunger-

pump, to supply the boiler-feed, and return the injection-water to the main. By P is denoted the lower pump; by P' the upper; *a*, *b*, and *c*, represent the apertures in connection with the indicator.

2707.



Dimensions.—Steam-Cylinder.—Length of stroke, 4 ft. 6 in.: diameter of cylinder, 24 in.; diameter of piston-rod, 3¼ in.

Pumps.—Length of stroke (average), 3·466 ft.; diameter of barrels, 20½ in.; diameter of piston-rods, 3 in.

Pump to turn Injection-water into the Main.—Length of stroke, 1·604 ft.; diameter of plunger, 8 in.

Fly-wheel.—Diameter, 20 ft.; length of crank, 27 in.

Boiler—One, Drop Flue.—Length of shell, 18 ft.; diameter of shell, 6 ft.: length of fire-grate, 5 ft.; width of each fire-grate during trial, 2 ft. 2½ in.: number of upper flues, 4; diameter of upper flues, 13 in.; length of upper flues, 11 ft.: number of lower flues, 9; diameter of lower flues, 7 of 9 in., 2 of 7 in.; length of lower flues, 9 ft. 8 in.

Explanation of Coaling Profile.—The profile of the coaling for seventeen hours will serve as an explanation of the form in which the register of coal consumed has been kept and plotted during the late experiments at Ridgewood and Prospect Hill. The hours selected have been taken rather than those at the commencement of the experiments, as profiles of steam and water pressures are given for the same period.

The firing was commenced on the morning of May 13, 1862, and the fires and water were got into the state in which it was determined to keep them as nearly as possible uniform. The coal was first noted at 0 h. 14 m. P.M., when 100 lbs. were thrown on one of the grates; at 1 h. 2 m. 100 lbs. on the other: at 1 h. 55 m., 60 lbs. on the first grate, and at 2 h. 32 m., 20 lbs. on the second. In this way the quantity of coal was taken every time any was put on, and on which grate it was thrown. The fire-box was divided in two by a brick wall, to maintain a more even fire. The coal was weighed in lots of 100 lbs. each, and the amount at each firing was then estimated. At

6.56 P.M.	.. ..	the total quantity fired was	.. ..	1155 lbs.
7.43 „	.. ..	90 lbs.	.. ..	1245 „
8.12 „	.. ..	100 „	.. ..	1345 „
9.03 „	.. ..	Cleaned fire No. 2.		
9.10 „	.. ..	120 lbs.	.. ..	1465 „
9.47 „	.. ..	115 „	.. ..	1580 „
10.27 „	.. ..	80 „	.. ..	1660 „
10.58 „	.. ..	80 „	.. ..	1740 „
11.30 „	.. ..	60 „	.. ..	1800 „

12.00 P.M.	Cleaned fire No. 1.	
12.06 „	100 lbs.	1900 lbs.
12.37 „	50 „	1950 „
12.56 „	50 „	2000 „
1.25 A.M.	70 „	2070 „
1.47 „	80 „	2150 „
2.22 „	50 „	2200 „
2.42 „	70 „	2270 „
3.02 „	90 „	2360 „

and so on. Each of the firings is represented by dots on the profile, and the dots are connected by lines. In this way the firing is graphically represented, Fig. 2708, and the quantity consumed during a period of a few hours can be quite accurately determined.

The firemen had been employed on board of ocean steamers, and had never been inside of the building till the experiments were commenced. They were directed to keep the water, as near as possible, a certain level, and their fires always in one condition. The boiler-pressure was varied from time to time, to test the comparative economy of the engine under different pressures and speeds. The watch of the firemen was twelve hours on and twelve off.

The coal used during the whole trial;—

	Lbs.
Of Delaware and Hudson Canal coal	11,800
Buck Mountain	2,360
Total	14,160
The total quantity of clinker ..	645
Small coal in ashes	383

2708.
COALING PROFILE.

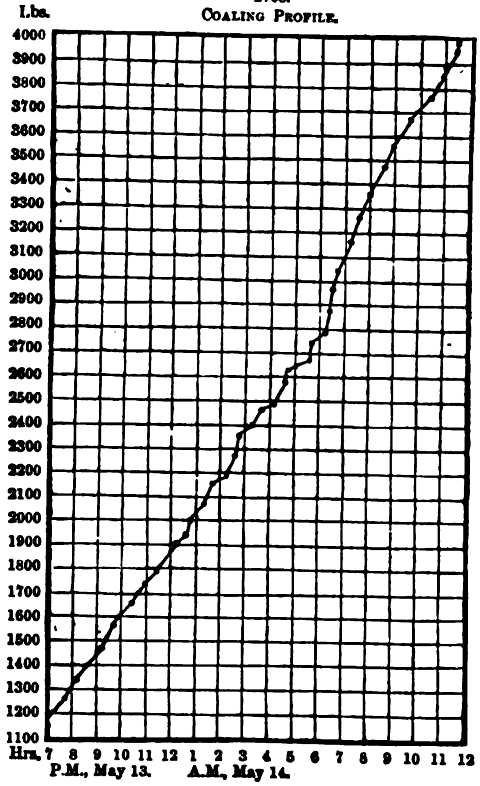


TABLE OF RESULTS OF EXPERIMENTS MADE ON PROSPECT HILL PUMPING ENGINE, MAY 13TH, 14TH, 15TH, 16TH, AND 17TH, 1862.

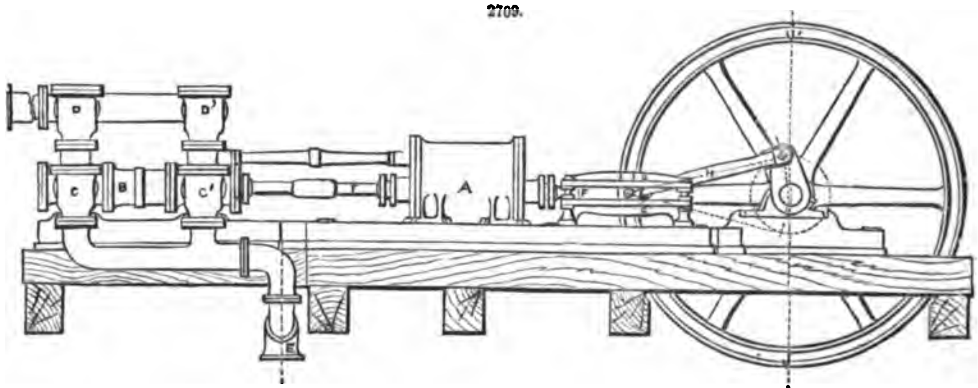
Date, 1862.		Number of Revolutions during the Hour. 1	AVERAGE. Mean Steam-Pressure per square inch in Steam-Cylinder. 2	Mean Water-Load per square inch in Pumps. 3	Boiler-Pressure per square inch. 4	Vacuum in Condenser. 5	Steam-Cylinder. Initial Pressure. 6	Cut-off. Full Stroke, 1·00. 7	Final Pressure below 0. 8	Gross Amount of Coal consumed during the Hour. 9	Remarks.]
Day.	Hour.		lbs.	lbs.	lbs.	inches.	lbs.		lbs.	lbs.	
May 13	8 P.M.	1478	22·3	28·7	47·6	27·3	42	·15	3·5	140	7 h. Ryan commenced firing.
	9 „	1487	21·7	27·8	47·3	27	39	·15	5	145	9 h. 3' cleaned No. 2 fire.
	10 „	1482	21·2	26·8	45·7	27	40	·18	5·5	160	
	11 „	1494	20·4	26·25	45·0	27·4	39·5	·14	6	140	
	12 „	1523	19·6	26·0	46·1	27·2	37	·15	6·5	140	12 h. 3' cleaned No. 1 fire.
May 14	1 A.M.	1578	19·15	25·5	45·1	27·2	35	·15	6	125	
	2 „	1600	19·15	25·25	44·3	27·5	34	·15	6	160	
	3 „	1638	19·25	26·6	46·5	27·5	38	·16	6	183	
	4 „	1686	19·5	27·3	48	27·5	38·5	·15	5·5	121	
	5 „	1720	20·1	27·8	48·5	27·5	39	·16	5·5	160	
	6 „	1775	21·9	20·3	47	27·5	38·2	·20	4	130	6 h. 30' Kenny commenced firing.
	7 „	1771	23·75	32·1	47·5	27·5	39	·20	4·5	285	
	8 „	1680	24·5	33·9	45	27·5	35·5	·17	3·5	260	
	9 „	1679	23·9	34·75	49·7	27·5	41	·19	3·5	210	9 h. 18' cleaned No. 1 fire.
	10 „	1675	24·1	35·15	45·8	27·5	41	·18	4·5	170	
	11 „	1670	24·1	34·9	45·6	27·5	42·5	·18	3·5	150	
	12 „	1669	23·4	33·5	51·1	27·5	42	·18	4	200	
	1 P.M.	1645	23·35	33·35	49	27·5	42	·18	4	200	
	2 „	1663	23·45	33·75	48·5	27·5	41	·19	3·5	190	2 h. 20' cleaned No. 2 fire
	3 „	1663	23·6	33·65	44·1	27·4	36	·19	3	220	
	4 „	1664	23·55	33·25	48·0	27·5	41·5	·15	3·5	213	
	5 „	1681	23·15	33·7	46·2	27·4	37·5	·18	3·5	185	
	6 „	1514	23·3	32·3	46·8	27·6	39·5	·16	4·5	120	6 h. 25' Ryan fires.

TABLE OF RESULTS OF EXPERIMENTS, &c.—*continued.*

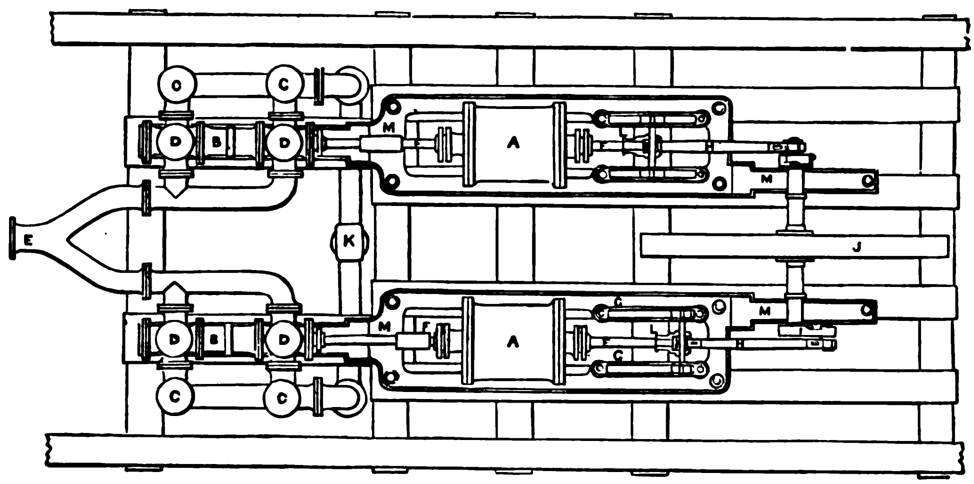
Date, 1862.		Number of Revolutions during the Hour.	Average. Mean Steam-Pressure per square inch in Steam-Cylinder.	Mean Water-Load per square inch in Pumps.	Boiler-Pressure per square inch.	Vacuum in Condenser.	Steam-Cylinder. Initial Pressure.	Cut-off. Full Stroke, 1·00.	Final Pressure below 0.	Gross Amount of Coal consumed during the Hour.	Remarks.
		1	2	3	4	5	6	7	8	9	
Day.	Hour.		lbs.	lbs.	lbs.	inches.	lbs.		lbs.	lbs.	
May 14	7 P.M.	1289	21·4	29·1	49·7	27·7	39·2	·15	4·5	125	
	8 "	1288	20·1	27·55	48·0	27·2	38·5	·14	5·5	105	
	9 "	1285	19·0	26·5	48·0	27·2	37·5	·15	6	110	
	10 "	1286	18·5	28·8	48·5	27·6	37	·14	6·5	140	10 h. cleaned No. 1 fire.
	11 "	1293	18·5	27·3	48·0	27·7	36·5	·15	6	150	
	12 "	1299	18·4	25·05	46·5	27·7	36·5	·15	6	120	
May 15	1 A.M.	1279	18·0	24·45	46·75	27·7	35·5	·15	6	120	
	2 "	1280	17·55	24·45	47·5	27·7	34·5	·13	6	130	2 h. 5′ cleaned No. 2 fire.
	3 "	1286	17·2	23·9	45·5	27·5	34·5	·12	6	125	
	4 "	1281	16·95	24·3	45·5	27·2	34·5	·13	6·5	116	
	5 "	1279	17·7	25·8	45·2	27·5	34·5	·14	6·5	140	
	6 "	1286	19·3	28·6	46·5	27·7	38	·17	5·5	110	6 h. 21′ Kenny fires.
	7 "	1276	21·55	31·7	45·5	27·7	38	·20	4·5	153	
	8 "	1258	22·65	33·55	37·5	27·7	32	·25	4·5	161	
	9 "	1255	22·35	33·5	33·5	27·9	29·5	·25	4	190	9 h. 25′ cleaned No. 1 fire.
	10 "	1254	21·85	32·1	34·7	27·9	31·5	·24	3·5	190	
	11 "	1256	21·3	30·5	34	27·9	30·5	·23	3·5	169	
	12 "	1258	21·1	30·0	34·5	28	31	·23	3·5	140	12 h. 32′ cleaned No. 2 fire.
	1 P.M.	1231	20·95	30·0	35·5	28	31·5	·20	4	150	
	2 "	1266	20·85	30·8	35·0	28	33	·24	4·5	110	
	3 "	1255	20·3	30·5	35·5	28	30	·22	5	134	
	4 "	1260	20·15	29·7	36	28	31·5	·21	5	110	
	5 "	1256	20·25	29·55	33	28	29	·23	4	115	
	6 "	1264	20·75	29·9	31·5	28	28·5	·26	4	119	6 h. 40′ Ryan fires.
	7 "	1233	20·75	30·65	33·5	27·7	29	·26	3·5	100	
	8 "	1277	19·9	27·6	32	27·5	25·5	·23	3·5	96	
	9 "	1260	18·6	26·8	31·5	27·5	25·5	·20	5	90	9 h. 38′ cleaned No. 2 fire.
	10 "	1264	17·95	26·65	31·5	27·5	24·5	·19	5·5	120	
	11 "	1267	17·8	26·4	31·5	27·5	26·5	·18	5·5	195	11 h. 18′ cleaned No. 2 fire.
	12 "	1266	17·9	25·95	32	27·5	25·5	·22	5·5	144	
May 16	1 A.M.	1252	17·7	25·5	27	27·6	21	·27	5	141	
	2 "	1244	17·35	25·35	21·5	27·7	17	·30	4·5	130	
	3 "	1241	17·35	25·35	21	27·6	17	·33	3·5	100	
	4 "	1238	17·5	25·35	21	27·6	17·5	·28	3·5	140	
	5 "	1239	17·8	25·9	20·5	27·7	17	·30	4	130	6 h. 30′ Kenny fires.
	6 "	1233	18·3	27·8	19·5	27·6	15·5	·42	2·5	160	
	7 "	1229	19·15	30·4	20	27·4	16·5	·38	1	164	
	8 "	1198	20·5	31·95	21	26·9	20	·37	1	125	8 h. 55′ cleaned No. 1 fire.
	9 "	1204	21·15	32·3	20	26·5	19·5	·43	1	130	
	10 "	1203	20·7	31·9	20·5	26·5	18·5	·38	1	150	10 h. 14′ cleaned No. 2 fire.
	11 "	1175	20·4	31·15	20	27	19	·35	2·5	204	
	12 "	1262	21·3	31·15	23	27·5	23	·31	2·5	205	12 h. 10′ Ridgewood fireman commenced firing.
	1 P.M.	1490	22·5	33·3	38	27·5	33	·18	3	155	
	2 "	1480	22·5	34·15	49	27·7	43	·19	3·5	120	
	3 "	1482	21·7	34·1	48·5	28·2	40·5	·19	3·5	190	3 h. 56′ cleaned No. 1 fire.
	4 "	1482	21·5	34·61	48·5	28·2	41	·20	3·5	165	
	5 "	1431	21·3	35·75	48·5	27·9	40	·18	4·5	190	
	6 "	1405	21·4	32·15	49	28	40	·19	4·5	195	6 h. 40′ Ryan fires.
	7 "	1403	21·35	32·35	48	27·9	40	·20	4	180	
	8 "	1406	21·45	31·7	49	27·5	40·5	·18	4	160	
	9 "	1404	21·5	30·0	50	27·5	41	·17	4·5	170	
	10 "	1408	20·7	28·75	49·5	27·5	40	·17	4·5	145	
	11 "	1396	19·4	27·95	49	27·5	38	·15	5·5	165	11 h. 50′ cleaned No. 2 fire.
	12 "	1356	18·7	27·15	47	27·6	37	·16	5·5	180	
May 17	1 A.M.	1267	18·3	26·7	47·5	27·6	34·5	·05	4·5	120	
	2 "	1313	18·6	26·75	49·5	27·5	32·5	·07	4·5	120	
	3 "	1308	19·15	26·95	49	27·5	31	·12	4·5	130	
	4 "	1333	20·0	27·15	49·5	27·5	35	·18	4·5	120	
	5 "	1385	20·75	28·5	48·5	27·5	39·5	·13	4·5	120	5 h. 30′ cleaned No. 1 fire.
	6 "	1382	20·95	32·8	47·5	27·1	39·5	·20	3·5	144	6 h. 30′ Ridgewood fireman commenced firing.
	7 "	1376	23·3	35·5	48	27	42·25	·21	2·5	166	
	8 "	1376	24·3	36·7	47·5	27	42·5	·21	2·5	150	
	9 "	1375	24·0	37·5	47	27	41	·22	2·5	150	

Ommanney and Tatham's Horizontal Pumping Engine.—This engine, Figs. 2709 to 2711, consists of a pair of horizontal double-acting pumps coupled together, as shown in Fig. 2711; it is placed in a

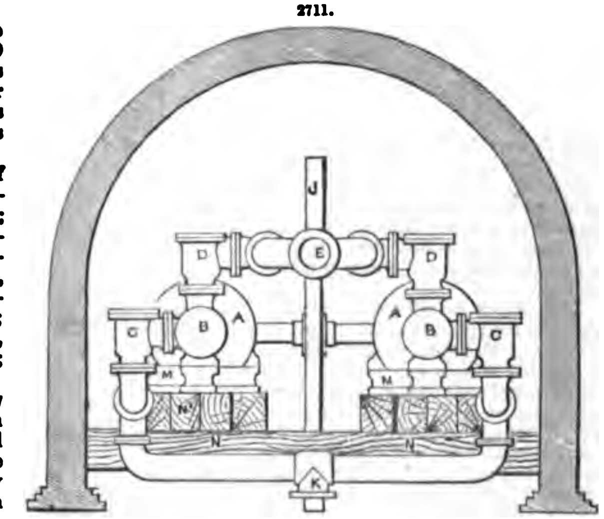
2709.



2710.



2711.



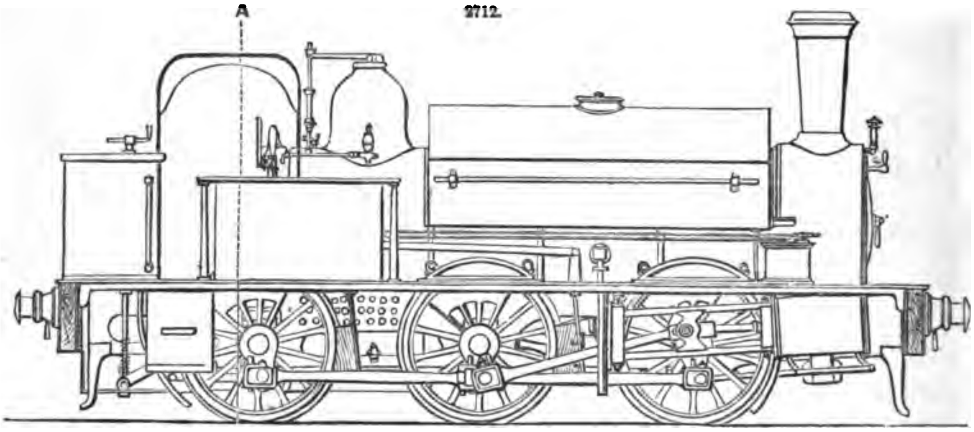
coal-pit in Staffordshire to force water up a vertical shaft of 900 ft. at one lift. The cylinders of this engine are 43 in. diameter and 36 in. stroke; the pumps 10½ in. diameter with brass Cornish *valves*.

In Figs. 2709 to 2711, of Ommanney and Tatham's engine, A A are the cylinders; B B, pump-barrels; *c c*, suction-clacks; E, the main delivery-pipe; F F, piston-rods; G G, slide-bars; H H, connecting-rods; I I, cranks; J, fly-wheel; K, main suction-pipe; L L, cross-heads; M M, engine-beds; N N, supporting beams.

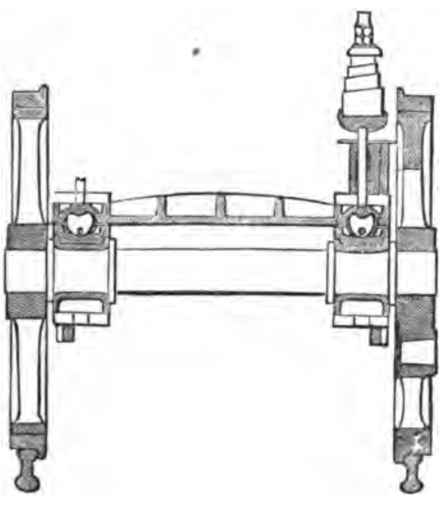
Tank Locomotive for Turning Sharp Curves.—We illustrate an arrangement for giving lateral play to the axles of locomotive engines, which has been lately designed and introduced with much success by Black, Hawthorn, and Co., of Gateshead-upon-Tyne, Figs. 2712 to 2714. Our figures show the arrangement as applied to the trailing axle of a class of six-coupled tank engines constructed for working the

traffic on colliery lines and similar branches, a class of work for which they are well adapted. This arrangement is nothing more than a substitute for the American *lateral motion beam*. On such lines sharp curves and heavy gradients are generally to be met with, and the engines employed on them should thus possess good hauling power, and yet should be carried on a short or flexible

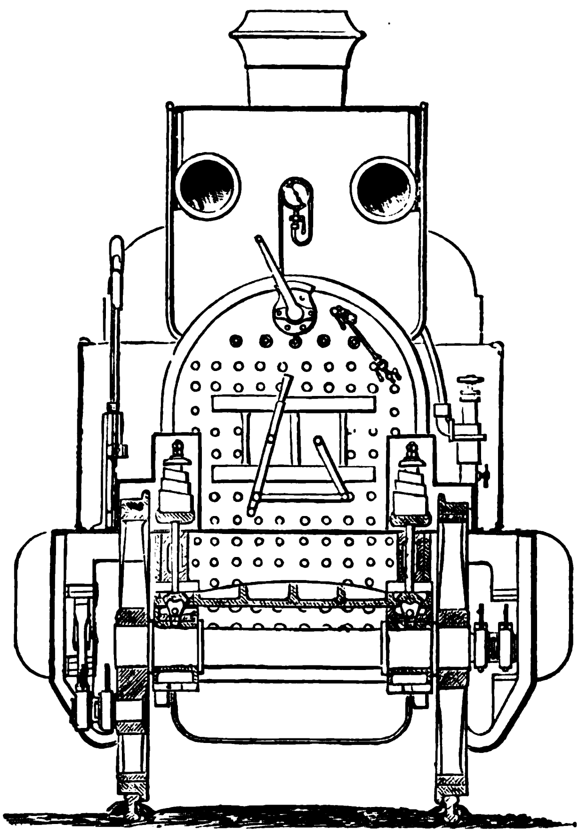
2712.



2714.



2713.



wheel base. For lines of this kind, where there is usually much shunting to be done, and where there are seldom facilities for turning the engine, tank locomotives are far superior to those with tenders, as indeed they also are for a great proportion of ordinary main-line traffic.

The engine to which our figures refer has outside cylinders 16 in. in diameter, with 24 in. stroke, and the six coupled wheels are 4 ft. 6 in. in diameter, and are arranged with a total wheel base of 12 ft. 9 in., the trailing axle to which the arrangement for giving lateral motion is applied being behind the fire-box. The quantity of water carried is about 950 gallons, part of this quantity being contained in a saddle-tank, and the remainder—about one-fourth of the whole—in a tank placed beneath the foot-plate at the trailing end. As this latter tank is at a lower level than the saddle-tank, the water in it is not used until the latter is empty, and it is therefore generally full of water, thus increasing the load on the trailing axle, which in six-coupled tank engines of this class is

generally too lightly loaded. The fuel is also carried at the trailing end, where there is a box capable of carrying about 35 cwt. of fuel. The weight of the engine is as follows;—

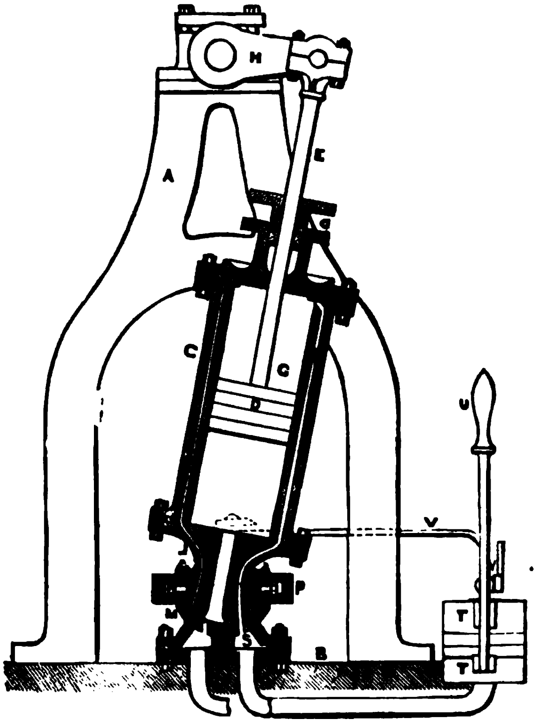
		Tons.
On leading wheels	.. ..	$11\frac{1}{4}$
„ centre „	.. ..	12
„ trailing „	.. ..	9
	Total	$32\frac{1}{4}$

The frame is of plates $1\frac{1}{16}$ in. thick, and is very strongly braced by cross and diagonal stays; cylinders are secured to each other by a strong box-girder, thus being, as it were, self-contained, and preventing a separate and independent strain on frames. All the working parts and tires are steel, and the slide-valves are equilibrium-valves. The boiler is double riveted in the longitudinal seams, the holes for rivets in all flanged plates being drilled instead of punched, and the whole of the boiler-plates being planed on all edges before being put together. The engine is worked at a pressure of 140 lbs. to the square inch.

Referring to Figs. 2712 to 2714 it is observable that the pressure of the trailing springs is received upon a casting which extends from one side of the engine to the other above the axle-boxes, this casting having at its under-side recesses and projections, which fit the upper edges of a pair of cams which are interposed between the casting and the axle-box crowns. These cams, which are made of steel, are heart-shaped, and they are retained in position by pins, which connect them to the axle-boxes. The axle-boxes are free to move laterally in their guides for a certain distance, and as they move to one side the cams each turn on one of their upper corners. It follows, from the shape of the cams and the relative positions of their bearing points, that when the axle is thus moved over to one side, the action of gravity tends to bring it back to its central position, and the movement, therefore, does not take place with any slight or ordinary oscillation of the engine, but is only caused when a certain pressure comes against the flanges of the wheels as the engine traverses a curve. It also follows, from the nature of the arrangement, that the pressure requisite to cause lateral movement increases in a certain proportion as the distance of the axle from its central position increases. The whole arrangement is very simple, and can be applied to existing engines in all cases where there is nothing to interfere with the lateral traverse of the wheels.

Oscillating Engine invented by James Hamer, of London. Referring to Fig. 2715, it will be seen that the cylinder of this engine is fixed upon a ball K, which works steam-tight in a cup M fixed to the bed-plate, this cup being provided with two ports or passages, the one being in communication with the boiler, and the other with the exhaust-pipe, by means of the pipes R, R. The ball has three ports formed in it, the central one communicating with the bottom, and the two outer ones with the top of the cylinder, these two outer ports being connected by an annular groove formed in the ball around the central port. The use of this annular groove is to enable the outer ports to communicate with the ports in the cup even when the cylinder has turned round so that a line drawn through the three ports in the ball would lie at right angles to the plane of oscillation of the cylinder.

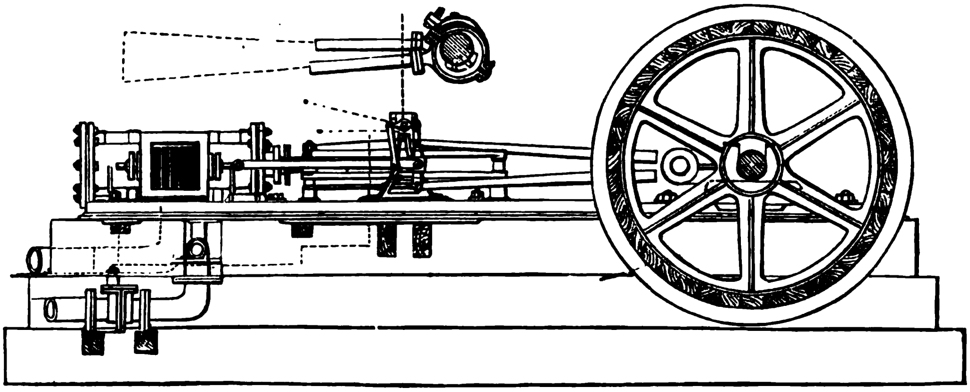
2715.



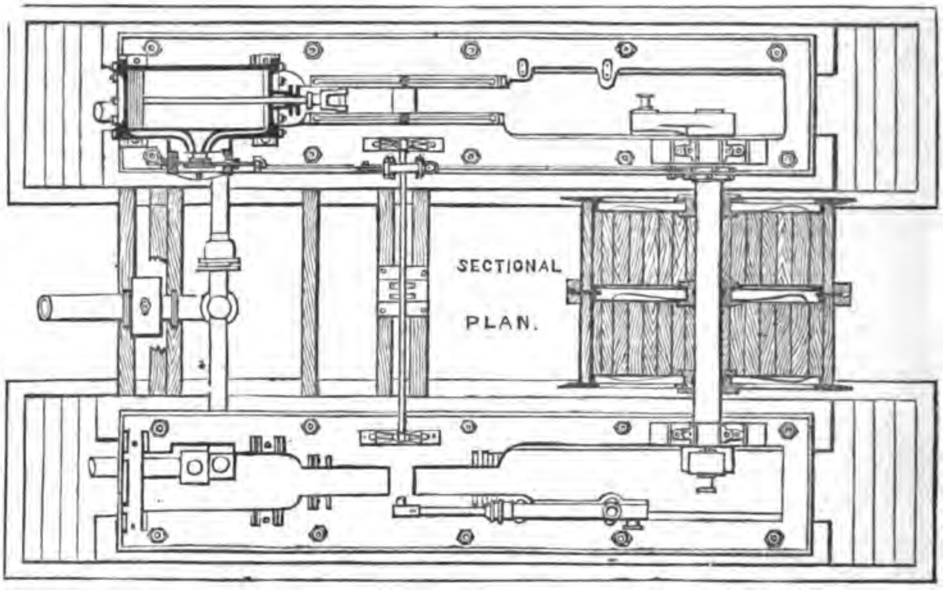
The ball is kept in place by a cap O and screwed ring P, and it will be readily understood that as the cylinder oscillates the movement of the ball in the cup regulates the admission and egress of the steam in the same way as an ordinary slide-valve having neither lap nor lead. It is found in working that a constant slow rotating movement of the cylinder takes place, and this movement conduces greatly to the equal wear of the cup-and-ball surfaces. To reverse the engine Hamer simply alters the course of the steam, making that which was the exhaust-pipe the steam-pipe, and *vice versâ*. Steam is led from the boiler to the chamber in which the valve T works; and by moving the valve T by means of the lever U, the engine can be stopped or started in either direction at pleasure. Hamer's arrangement, with a fly-wheel, will be found useful where the power required is not great.

Winding Engine of Fletcher, Jennings, and Co.—This engine, Figs. 2716 to 2718, which has been made at a hematite iron-ore mine in the Cumberland district, although it does not present many

2716.



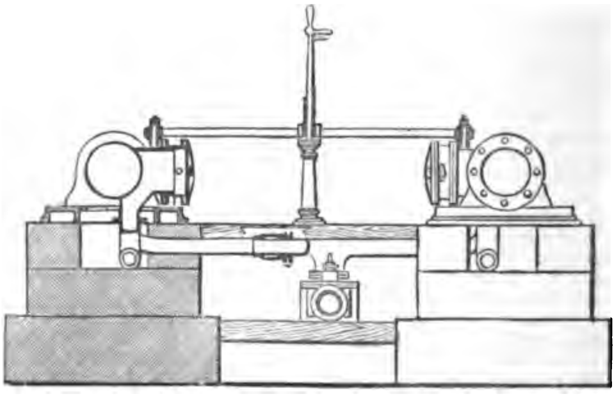
2717.



features of novelty, it affords a good example of modern winding engines of medium size. Coupled horizontal winding engines are now almost always employed, both for colliery and ore mines, in preference to beam, direct-acting vertical, or any other form of single engine.

In the present example the different parts seem to be massive and well proportioned, with strong heavy bed-plates. The cylinders are 20 in. diameter, and the pistons have a stroke of 4 ft.; the cranks in this instance are of cast iron, though the makers generally prefer and recommend wrought-iron ones. The main

2718.



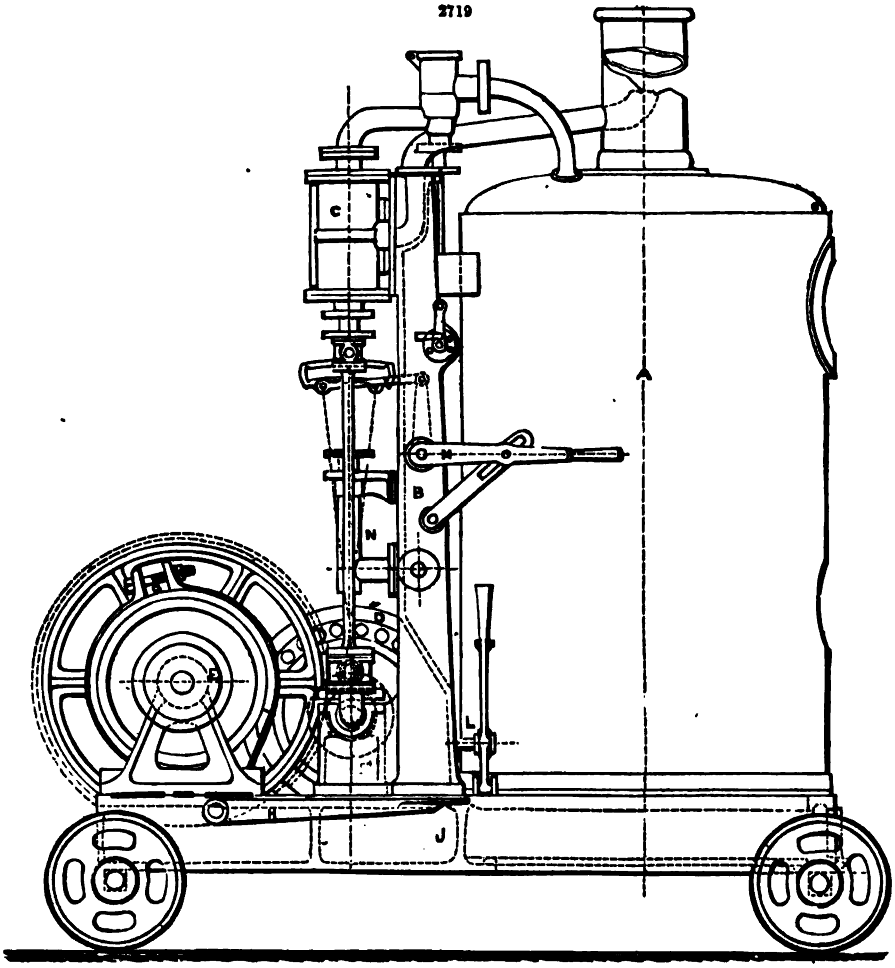
shaft is of wrought iron, 9½ in. diameter on the body, and 8 in. diameter in the journals. There is no fly-wheel attached, and the rope barrels, which are constructed for round ropes, are placed upon the engine-shaft, and are 8 ft. diameter. They are divided in the centre by a series of wooden cribs of elm which form a brake-sheave, which is operated upon by a wrought-iron strap not shown in the figures, but the action of the whole will be easily understood. See BRAKE.

The valves are ordinary slides, and are worked by means of two *eccentrics* to each, and the ingenious straight link-motion invented by Alexander Allan, p. 1199. The application of this link and winding engines is particularly valuable, especially where the valve is unbalanced, as reversing is effected with great facility. In some larger examples these makers balance the slide-valves by means of the thin flexible plates connected with them by links.

Chaplin's Hoisting Engine, on cast-iron sole-plate, Figs. 2719 to 2721, for use on shore or on shipboard. Manufactured by Wimshurst and Co., London.

A, boiler; B, engine-pillar; C, cylinder; D, fly-wheel; E, winding shaft or barrel; F, *winch ends;* G, *brake;* H, brake foot-lever; J, sole-plate or carriage; K, disengaging *clutch;* L, clutch lever and rod; M, reversing lever to link-motion; N, feed-pump.

2719



N. P. Burgh's Single or Double Acting Steam-Pump.—The mechanical arrangement of the valves of this pump, in relation to the piston or plunger, is in harmony with a well-known principle of hydraulics, namely, when any volume of water and air intermingled becomes compressed, the air, being the lighter, ascends, and the efficiency of pumps therefore consists chiefly in the discharge of the air before the water.

By this invention Burgh proposes to arrange and obviate the difficulties heretofore met with, in the following manner;—The valves for the purposes of admitting and permitting the supply and discharge into and from the pump can be arranged either horizontally, vertically, or otherwise, to suit the particular purpose for which they may be intended.

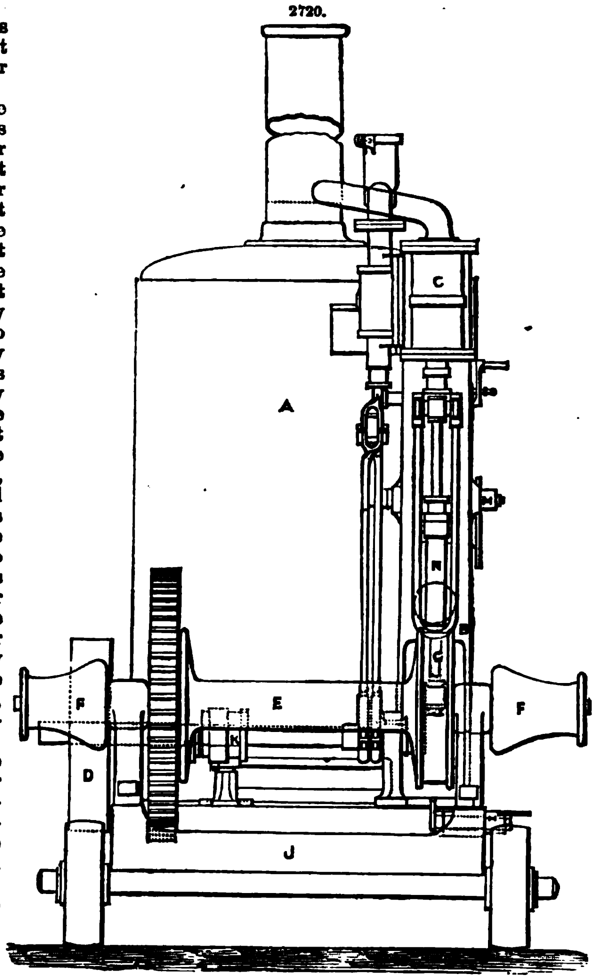
He proposes to place each valve side by side, above and below, or at each end of the barrel of the pump. The supply-valve on the top opens towards the barrel, and that at the bottom in the opposite direction, so that they work towards each other. The discharge-valves are situated at or

near the same angle or level as the supply valve or valves, but work in opposite directions or from each other.

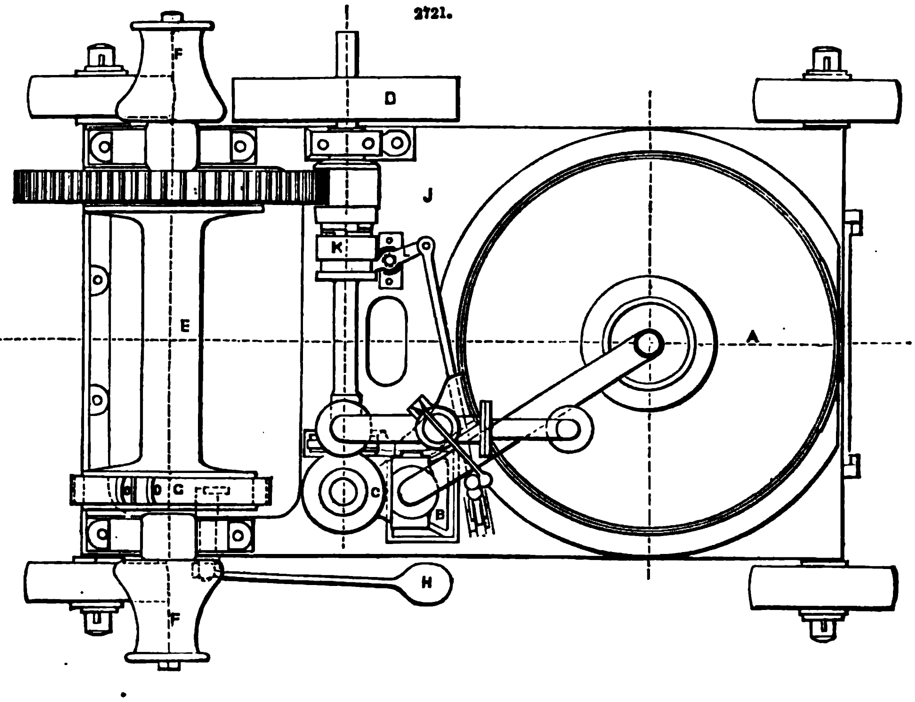
This invention presents a more compact arrangement of the valves than those previously used for the same purpose, inasmuch that the air admitted with the water into the pump is nearly, if not entirely, discharged at each stroke of the plunger or piston, so that the next following stroke of the piston or plunger is equal to that preceding it, by which means any accumulation of air in the pump is prevented, and the efficiency of the upper and lower portions of the pump is rendered equally effective by the positions of the valves. To further ensure that the air below the piston, in the case when the pump is vertical, shall be as completely discharged as the air at the top, the piston is grooved in its periphery in one or more places sufficiently to allow the air when the piston is descending to escape to the upper portion of the pump, and on the up-stroke of the piston this air and the water will be effectually discharged. The piston may be solid or fitted with rings, valves, or otherwise, to suit the circumstances.

In this arrangement when the pump-valves are of metal or other suitable material, the top supply-valve and the lower discharge-valve being inverted in the case of vertical pumps, it is proposed to fit them with springs, of any kind of material suitable to the particular requirement, above or below the valves to retain them

2720.



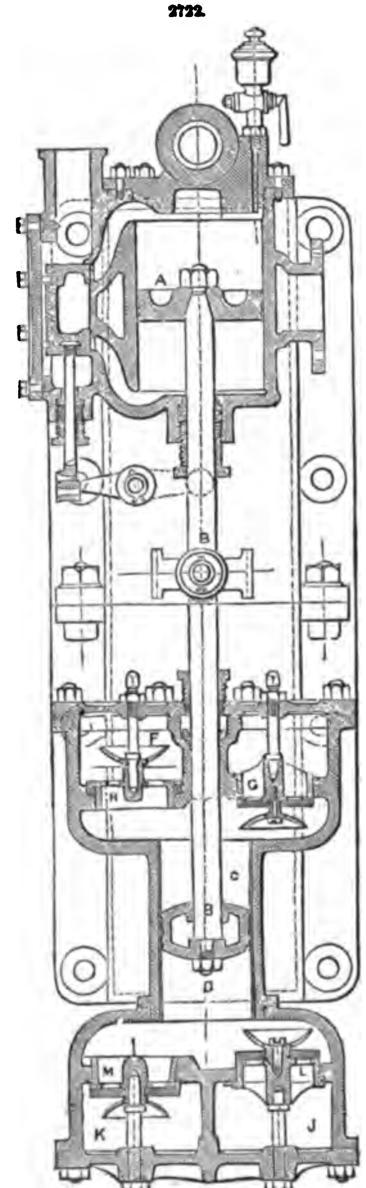
2721.



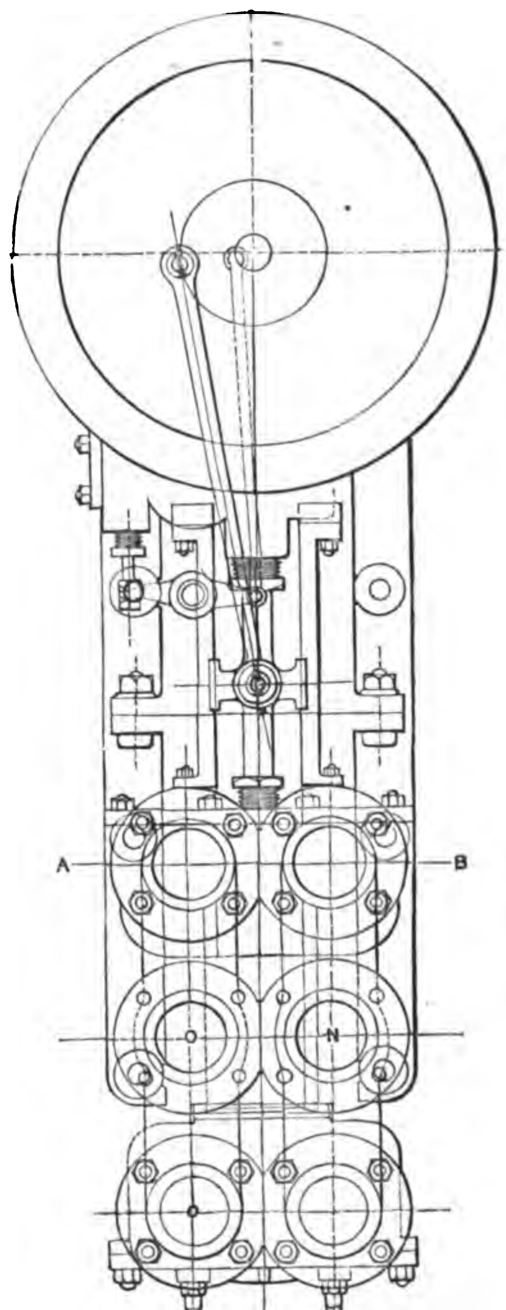
in an equilibrium position, so as to enable them to close at the proper time. If necessary, india-rubber, canvas, or other flexible valves may be used for the specific purpose just described with the requisite seatings, and guards or valves of any shape, form, or material, as a combination is also applicable if deemed necessary.

This arrangement possesses the advantage that a single-acting pump can be made to perform perfect duty on account of the discharge-valve being in such a position that the air admitted by the supply-valve is perfectly discharged with the fluid.

2722.



2723.



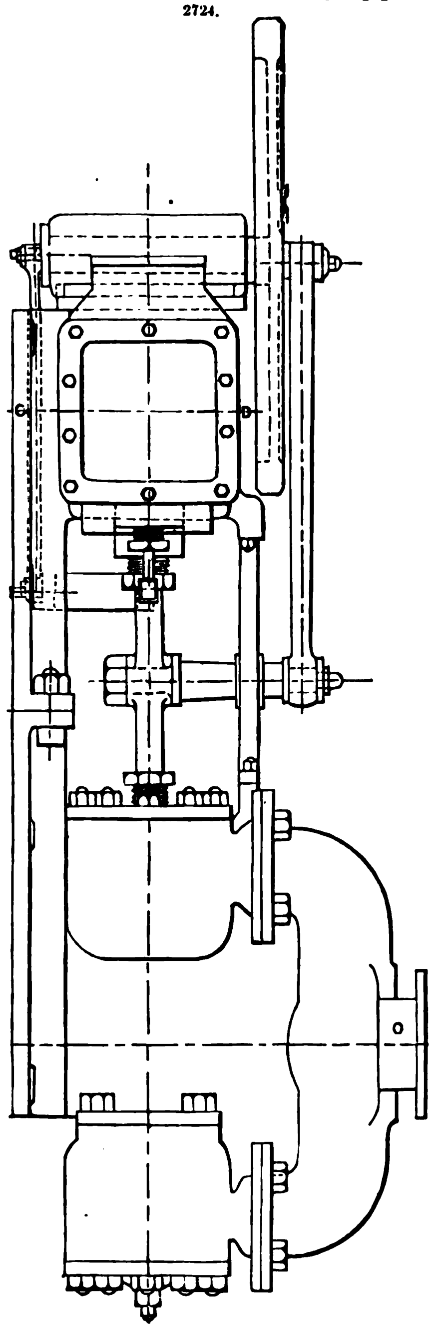
For air-pumps this arrangement is also particularly applicable, because the entire contents is discharged at each stroke of the piston or plunger.

Fig. 2722 is a sectional elevation of this machine as applied to a double-acting pump, and Fig. 2723 a front elevation; Fig. 2724 is a side elevation of Fig. 2722; Fig. 2725 is a sectional

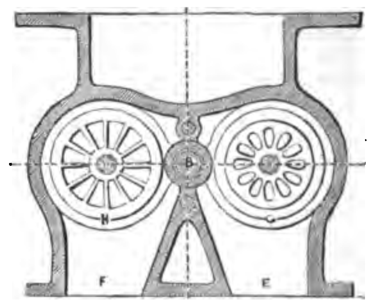
view in plan taken on the line A B, Fig. 2723; Fig 2726 is an elevation in plan of Fig. 2723; and Fig. 2727 a sectional plan of Fig. 2724.

In each of the figures the same letters refer to corresponding or similar parts;—A is the steam-piston connected to the rod B of the pump-piston C working within the barrel D. On the upper

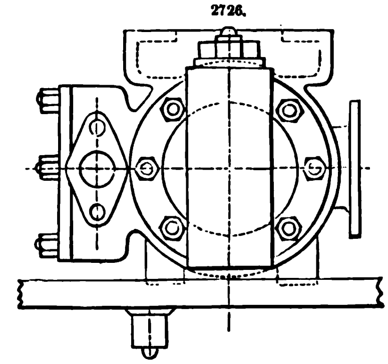
2724.



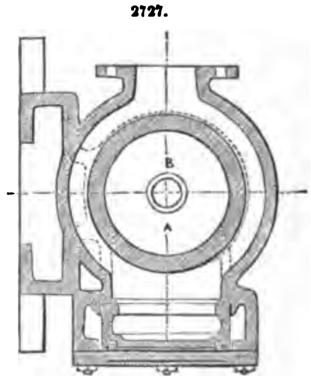
2725.



2726.



2727.



portion of the barrel two separate chambers E and F are cast therewith, forming the suction and discharge chambers E and F, in the bottom portions of which are secured in a suitable manner the seatings and valves G and H for suction and discharge. At the lower end of the barrel D there is bolted a casing containing two chambers J and K, in the bottom of which are secured similar valves, L and M, as those above referred to, G and H. The four chambers, just named, have branch

pieces cast with flanges, the two suction and two discharge chambers are joined together by means of two branch or coupling pipes N and O, and thus forming a single suction-opening and a single discharge-opening for the working connections.

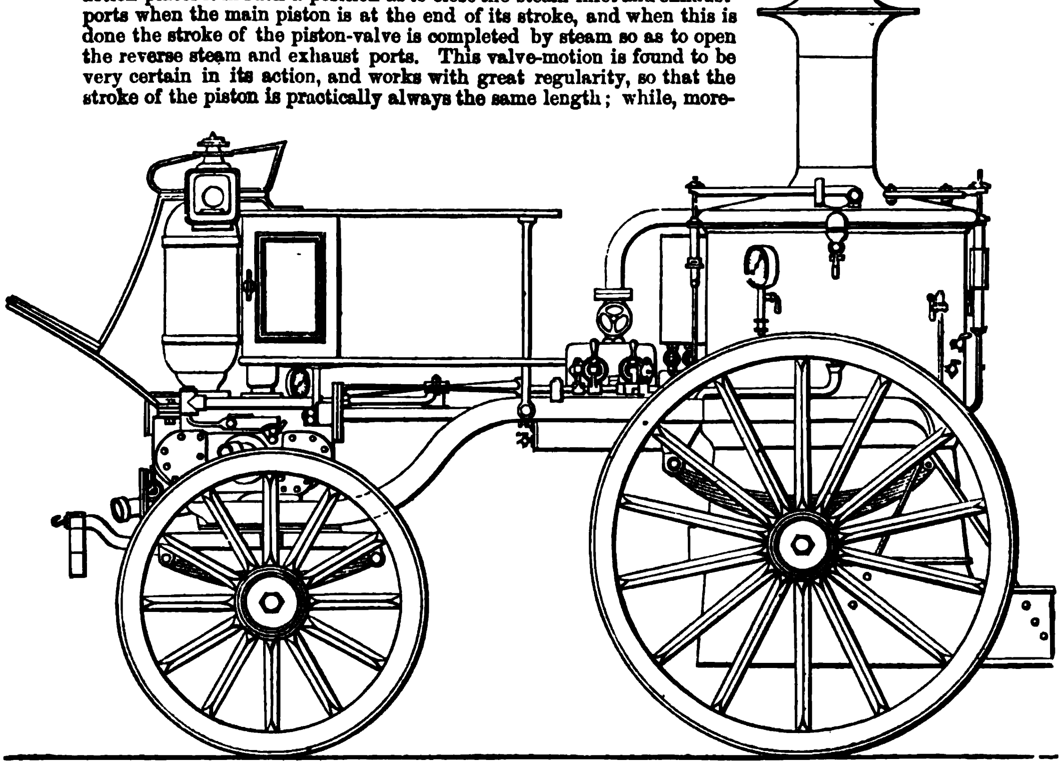
It will be seen on referring to Fig. 2722 that on the piston C moving in either direction, that is, up and down or right and left, the valves G and L open and admit water into the barrel on each side of the piston C, or at each end of the barrel, and at the same time the valves H and M permit of the discharge therefrom, by which means a continuous and effective supply and discharge are produced.

The main feature is that should any air be admitted into the barrel, by this arrangement of the valves it is drawn out by the piston C at each stroke, and thus a continuous uniform action of the valves, and the special duty of the piston C, are fully carried out.

Merryweather's Steam Fire-Engine, Figs. 2728 to 2732.—This engine weighs but 20 cwt.; it is mounted on high wheels and easy springs so that its draught is light, and it is capable of delivering 200 gallons a minute, and of throwing a ⅞-in. jet 150 ft. high, or two ⅝-in. streams. In its chief parts the engine is of similar construction to the larger engines manufactured by the same well-known makers of steam fire-engines. The *boiler*, which is shown in vertical section, Fig. 2729, is constructed according to Field's arrangement, and is of a kind well adapted for use on a steam fire-engine. The sides of the fire-box it will be noticed are formed entirely of Field's tubes clustered together. The boiler possesses the advantage that if the water is allowed to get low the only parts damaged are the tubes, and these all can be taken out and replaced in fourteen hours. A single tube if damaged can be taken out and replaced in half an hour, or the hole can be plugged if preferred. In the boiler, Fig. 2729, the tube and top plates and uptake are of iron, while the shell is of mild steel and double riveted. The tubes are of solid drawn homogeneous metal, and the boiler is tested up to a pressure of 300 lbs. a square inch

A strong frame of angle-iron, well stayed, is attached to the boiler by strong independent wrought-iron horn pieces, and on this frame, over the fore and hind carriages, are fixed the steam and pump cylinders, so that no working parts are attached to the boiler. The piston-rod is in one piece, the steam-piston being attached at one end and the pump-piston at the other end. In the centre of the piston-rod is keyed a light cross-head carrying a brass clip, which, as it moves to and fro, glides along a slightly twisted bar, giving it a rocking motion which imparts a reciprocating movement to a finger-lever, and this lever actuates a single slide-valve of equilibrium-piston form. This valve is so arranged that a fixed action places it in such a position as to close the steam-inlet and exhaust-ports when the main piston is at the end of its stroke, and when this is done the stroke of the piston-valve is completed by steam so as to open the reverse steam and exhaust ports. This valve-motion is found to be very certain in its action, and works with great regularity, so that the stroke of the piston is practically always the same length; while, more-

2728.

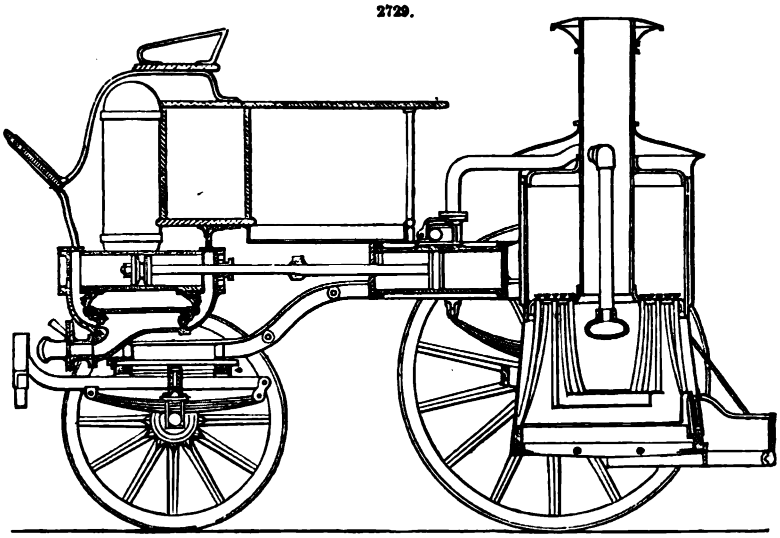


over, the engine is so much under control that it can be run at only one stroke a minute, or at any intermediate speed up to one hundred and sixty or more double strokes per minute.

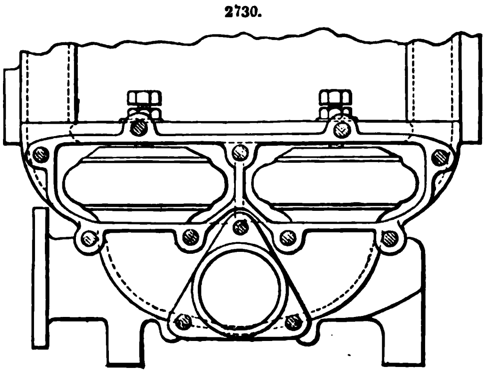
The pump-cylinder, Figs. 2730, 2731, is cast with its valve-chamber entirely of gun-metal, and is fitted with india-rubber valves. These valves have very large clear openings without gratings,

and with but moderate lift, and are so arranged that immediately the engine has been stopped all water leaves the pump, thus preventing accidents from freezing. These engines possess an advantage, the importance of which is very great, and that is the almost absolute freedom of the pumps from liability to become choked or set fast with sandy water, a defect which, when it exists, not only gives rise to permanent injury to the pumps, but also causes, after a few hours' working, a loss of power of from 35 to 50 per cent. in the useful effect, a loss which continues until the pumps have been taken to pieces and cleaned.

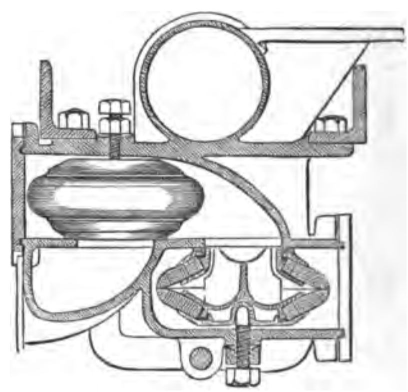
2729.



2730.



2731.



At the side of the main pump is the feed-pump taking its supply of water from the delivery passage of the main pump, and regulated by a cock with a graduated index plate. When the water pumped by the main pump is salt or foul, as it is in some cases, fresh water is supplied to the boiler by opening another suction-cock to the same feed-pump, there being attached to this cock a short suction-hose which is placed in a pail or tub of fresh water as with a portable engine. The feed-pump has a brass-cased ram attached to the main cross-head, and it can be used for feeding the boiler without passing water through the main pump; while, moreover, in case the boiler be carelessly allowed to get short of water, the main pump by working the engine slowly can discharge all its water direct into the boiler.

The main pump is fitted with copper suction and delivery air-vessels, and a pressure-gauge and two delivery-outlets, each with stop-valves screwed to receive the couplings of delivery-hoses. The engine has a driver's seat, seats and room for twelve firemen, and foot-plate behind the boiler on which the stoker rides and attends to the fire whilst *en route*, as the fire-door is at the hind end between the two coal-bunkers. These latter carry more than an hour's supply of coal, and there are brackets provided for 30 ft. of suction-hose, bunker for 280 ft. of leather delivery-hose, and a tool-box for branch pipes, nozzles, and other small things that may be required. A pole and swing-bars are also provided so that two horses may be attached when required. These engines are not only effective when water is close, but they have the power to pump water through delivery-hose 1500 or 2000 ft. long, and yet to deliver a good jet of water at the end. The steam-cylinder is $5\frac{1}{2}$ in.

diameter, and the double-acting pump 4½ in. in diameter, the stroke of both steam and water pistons being 12 in.

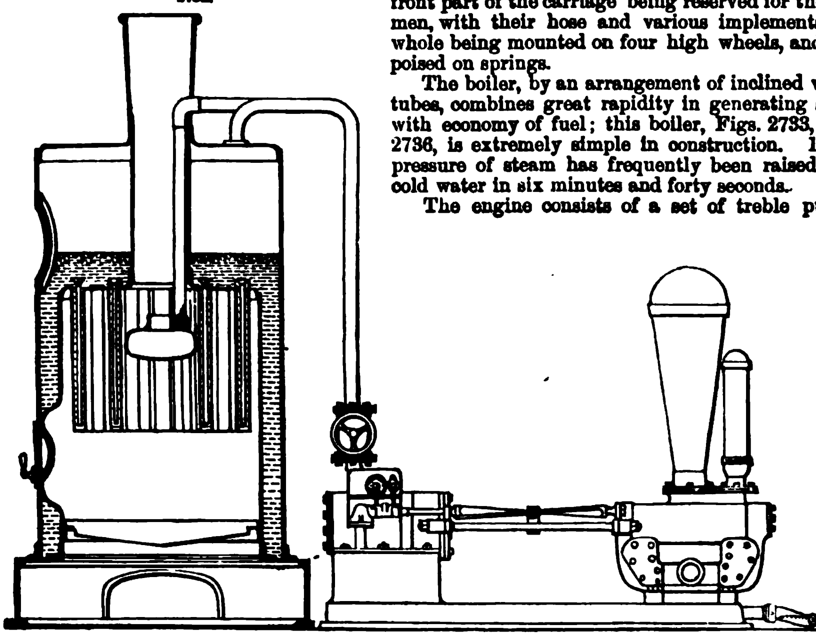
Altogether we consider that the engine just described is well planned, and that the details are well carried out.

Fig. 2732 represents one of Merryweather's steam fire-engines which can be used afloat to extinguish fires on shipboard.

Shand, Mason, and Co.'s Equilibrium Steam Fire-Engine.—The boiler and pumps of this engine are conveniently placed, close to the hind axle; the front part of the carriage being reserved for the firemen, with their hose and various implements, the whole being mounted on four high wheels, and well poised on springs.

The boiler, by an arrangement of inclined water-tubes, combines great rapidity in generating steam with economy of fuel; this boiler, Figs. 2733, 2735, 2736, is extremely simple in construction. 100-lb. pressure of steam has frequently been raised from cold water in six minutes and forty seconds.

2732.



The engine consists of a set of treble pumps, which are worked direct by a corresponding set of treble steam-cylinders, the whole being fixed to the boiler.

Fig. 2733 is a longitudinal section.

Fig. 2734 is an end elevation.

Fig. 2735 is an elevation of the tube-chamber, showing the arrangement of the tubes.

Fig. 2736 is a plan of the tube-chamber for the same purpose.

A are steam-cylinders; A_1, fire-box; A_2, fire-bars; A_3, combustion-chamber; A_4, chimney; A_5, steam-chest; B, plungers; C, connecting-rod; C_1, safety-valves; C_2, exhaust-pipes; C_3, steam-pipe; C_4, steam-regulating valve; D, engine-frame; D_1, feed-cistern; D_2, hose-box; D_3, driver's seat; D_4, driver's footboard; D_5, boot to carry hose, and support locking; D_6, lockings; E_1, front wheels; E_2, rods by which hind footboard is suspended; E_3, hind springs; F, connecting-rods; G, stuffing-box of plunger; H, cranks; H_1, tubes in boiler; I, crank-shaft; J, eccentrics; J_1, feed-pump; K, bucket; L, foot-valve; L_1, foot-valve joint; M, suction-nozzle; N, suction-chamber; O, pump-barrels; P, pump-head; Q, delivery-nozzles; Q_1, delivery-valve handle; R, hind axle; S, fire-door in boiler; T, hind footboard; U, hind wheels; V, air-vessel; W w, front-spring shackles; x, front axle; Y, front springs; Z z, hind-spring shackles.

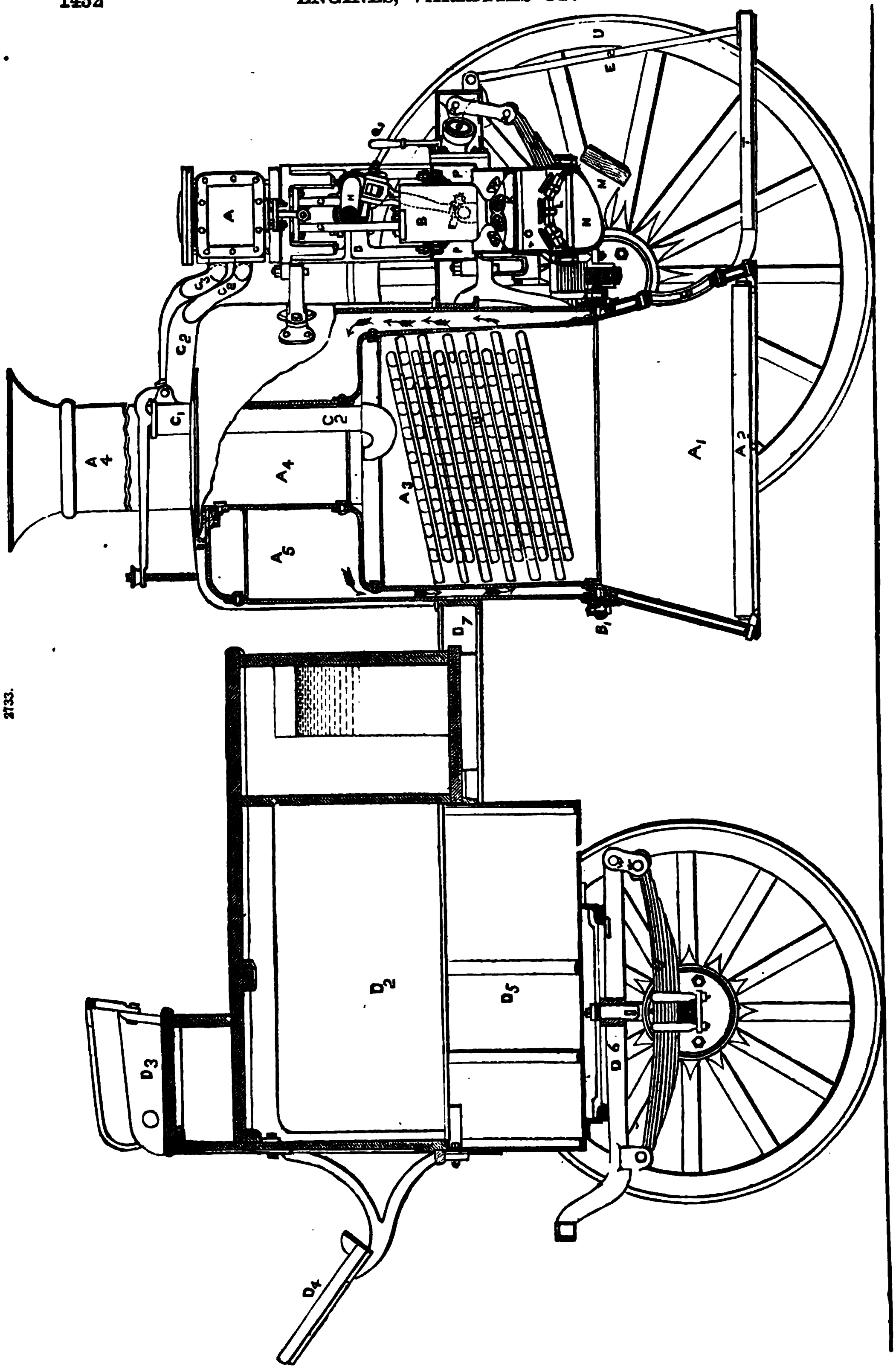
There are three steam-cylinders and three pumps direct acting, on the bucket-and-plunger type, the plunger being half the area of the buckets. The buckets are bolted to the plungers, and are shown at K, in Fig. 2733. The foot-valve is shown at L in the same figure. Access is obtained to the valves by unscrewing the bolts L, and dropping the suction-chamber N, with the foot-valves, bodily down, then the bucket can be disconnected from the plunger and dropped down in the same manner. The foot-valve is made fast by sweating to its seating.

The suction-hose is screwed to the nozzle M, and the delivery-hose to the nozzles Q Q.

When all is placed ready for starting, the engine, by lifting the bucket, fills the pump-barrel O, and on the return stroke (down) the water is transferred through the bucket K into the upper side of the pump-barrel; but at the same time half of the quantity is discharged by the plunger, and the other half remains to be discharged by the next up-stroke by the bucket. An air-vessel V, Fig. 2734, is in communication with the pump-head.

The boiler is of the water-tube class, having the tubes arranged in separate layers, and each layer at right angles to the one immediately above or below it; they are also inclined, to ensure a circulation of the water, which goes on in the direction shown by the arrows, Figs. 2733, 2736.

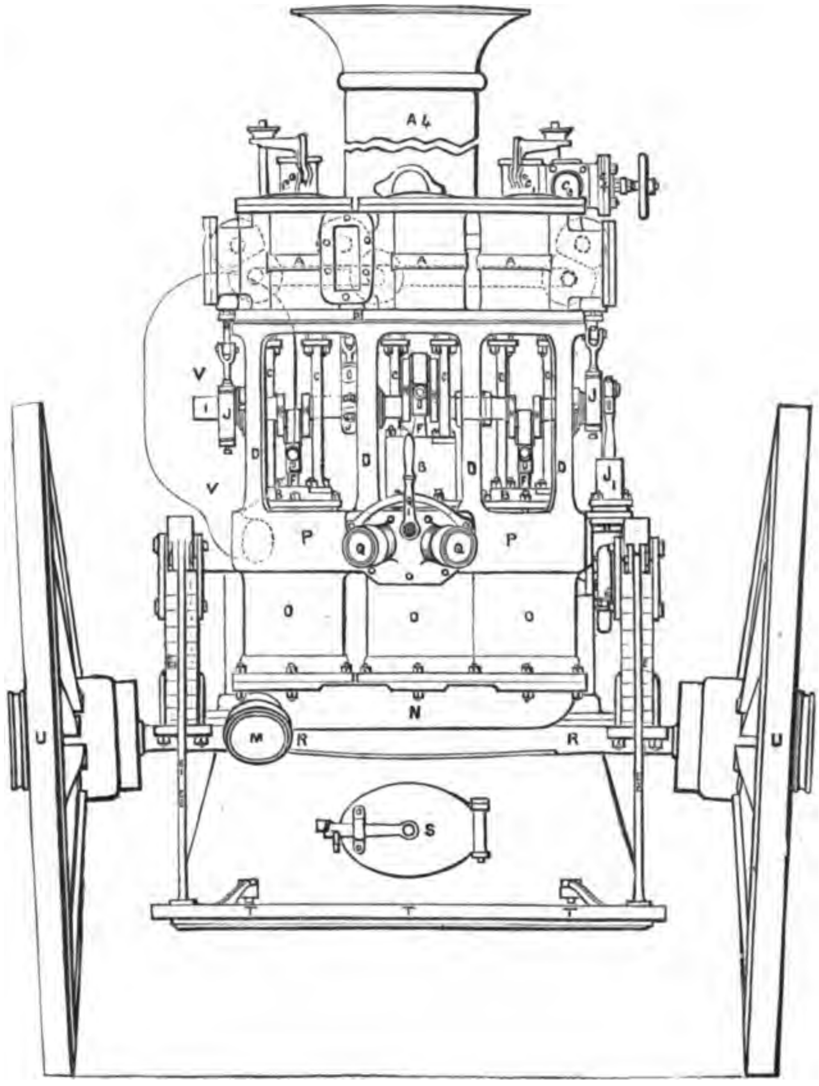
When it becomes necessary to examine the boiler, it can be readily done by unscrewing the bolts at B_1 and B_2, Fig. 2733, and lifting the shell entirely off; then every one of the tubes are exposed.



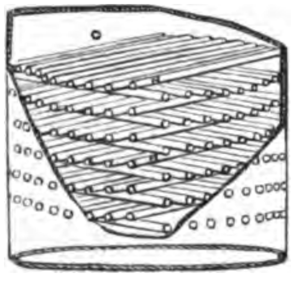
2733.

The springs are provided with shackles W, Fig. 2733, on their hind ends, to give play without injury to the machine.

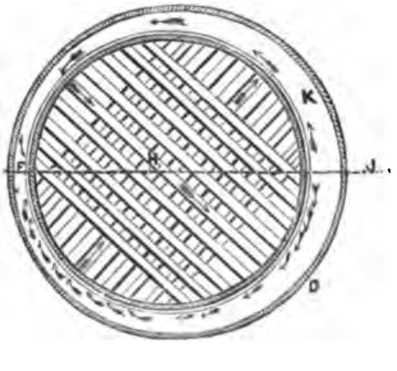
2734.



2735.

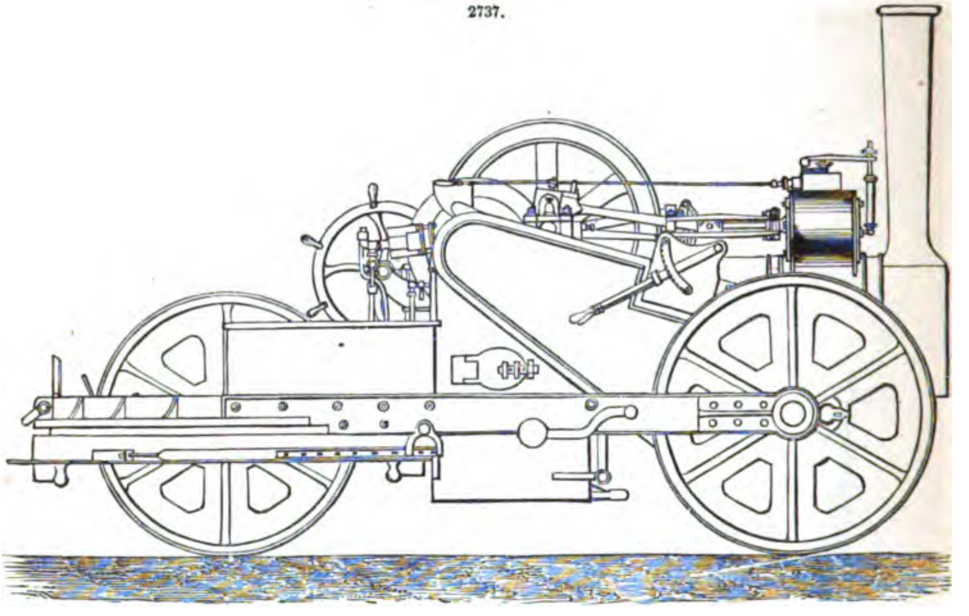


2736.

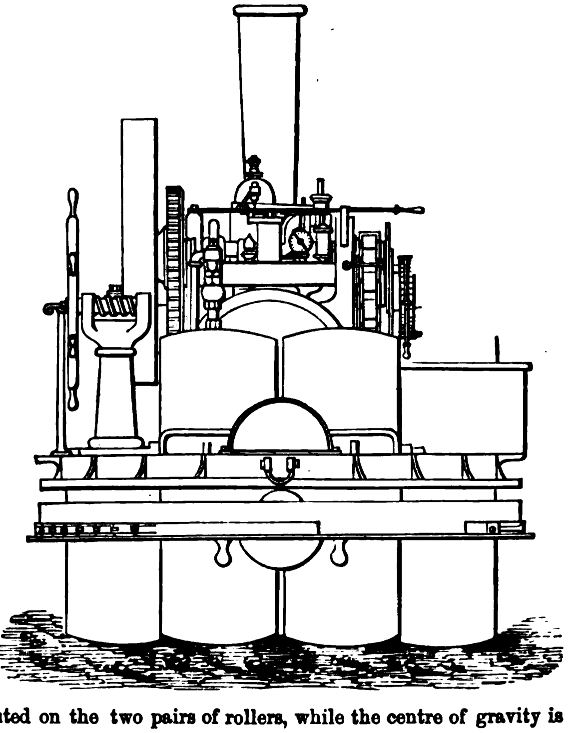


Steam Road-Roller of Aveling and Porter, of Rochester.—This machine, Figs. 2737, 2738, weighs 15 tons, and is mounted on four broad wheels or rollers, the front pair, which are 5 ft. in diameter, acting as the driving wheels; these rollers are so placed that the total width rolled is 6 ft. The hind pair of rollers, which are 4 ft. 9 in. in diameter, are placed close together, so as to form, as it

2737.



2738.



were, one broad roller, and they are of such width that they slightly overlap the tracks of the front rollers, as shown in the back elevation, Fig. 2738. The hind rollers are mounted within a ring acted upon by the steering gear, the hand wheel of which is situated on one side of the engine. The mounting of the hind rollers is, moreover, so arranged that the machine can, as it were, rock on them to some slight extent, and the front wheels are thus left free to adjust themselves to the curvature or inequalities of the road. The machine is practically supported on three points, the most stable arrangement that can be employed.

The general arrangement of the steam-cylinder and gearing is the same as that ordinarily employed by Aveling and Porter on their well-known traction engines, and all parts are readily accessible and completely open to inspection. The fire-box is provided with a side door, the firing being performed by the driver, who stands on one side of the engine, while the steersman stands on the other. The fuel and water are carried upon the strong framing, which connects the hind rollers with the fore part of the machine, and the weight is arranged so that it is equally distributed on the two pairs of rollers, while the centre of gravity is kept as low as possible.

At Manchester a road-roller, similar to that we are now describing, rolled down a surface of 2225 sq. yds. of newly-metalled road in ten hours with a consumption of 6 cwt. of coke; while

on another occasion 600 sq. yds. of similar road were rolled down smooth in 2½ hours, the consumption of coke being three bushels.

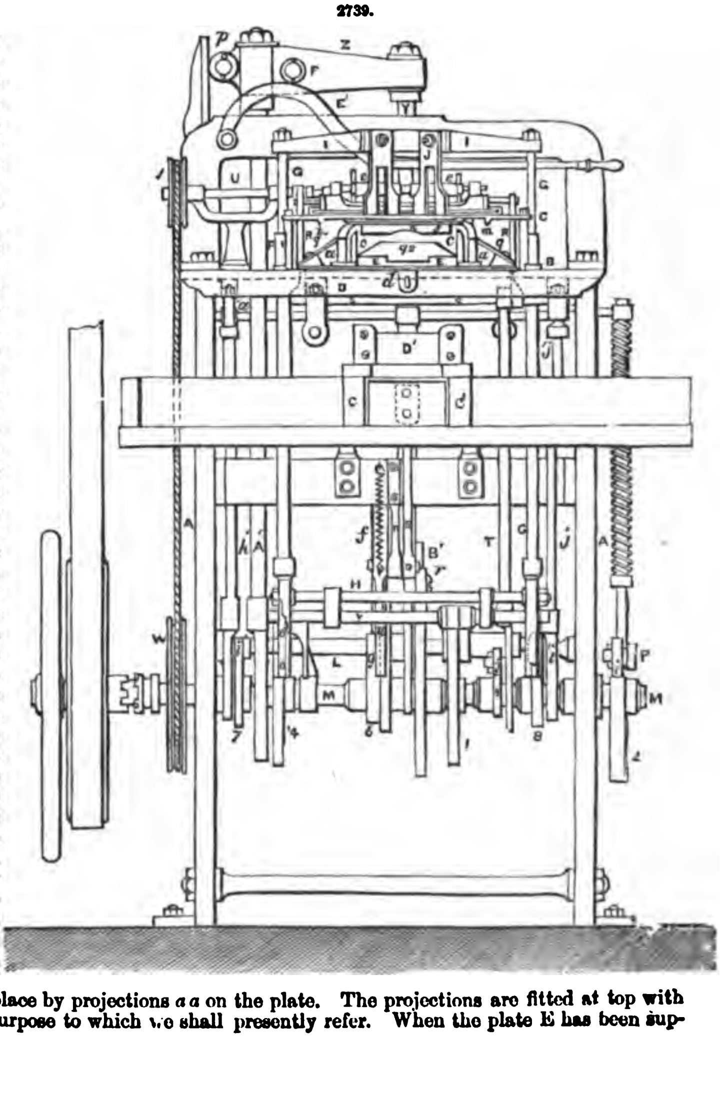
Besides road-rolling, the machine can, by merely placing spikes in holes provided in the wheels to receive them, be also employed for breaking up the roads. The machine at Manchester was tested with this class of work, and picked up an area of 2048 sq. yds. in three hours forty minutes, with a consumption of 160 lbs. of coke. The cross-picking was subsequently performed by hand-labour, the amount of this hand-labour being only equal to that of one man working sixty hours. See Agricultural Engines. Agricultural Implements. Air-Engine. Blowing Machine. Boring and Blasting, p. 515. Bridge, p. 793. Cam, p. 904. Coal-cutting Machine. Copper, p. 1070. Dredging Machine. Drill.

ENVELOPE MACHINE. Fr., *Machine à plier les enveloppes;* Ger., *Couvertfaltmaschine;* Ital., *Macchina da copertine;* Span., *Máquina para hacer sobres.*

Self-feeding Envelope-folding Machine.—The credit of inventing this machine is due to G. H. Reay, of New York.

To thoroughly appreciate the advantages these machines present, our readers must bear in mind that other machines require three attendants to perform the operations carried out by these, which require one attendant only. There is the attendant to feed with one blank at a time; and as ordinary machines deliver the envelopes simply creased, another attendant must place the flaps of the envelopes in proper order and gather them up, whilst a third attendant is required to band them. In the machine we are about to describe, the attendant sits down in front and places in the proper receptacle a certain number of blanks, regulated according to their substance; the apparatus picks up the blanks singly and conveys them to the creasing-box, and, during their progress, they are stamped, if so required. After having been creased, the envelopes are, by a double action of the plungers, most securely and correctly fastened and folded. After leaving the plungers, they are mechanically collected and delivered to the attendant in symmetrical order ready to be banded. Thus, from the time the blanks are delivered to the machine till the perfect envelope is turned out, the attendant has nothing to do with them, which leaves ample time to band them up.

2739.

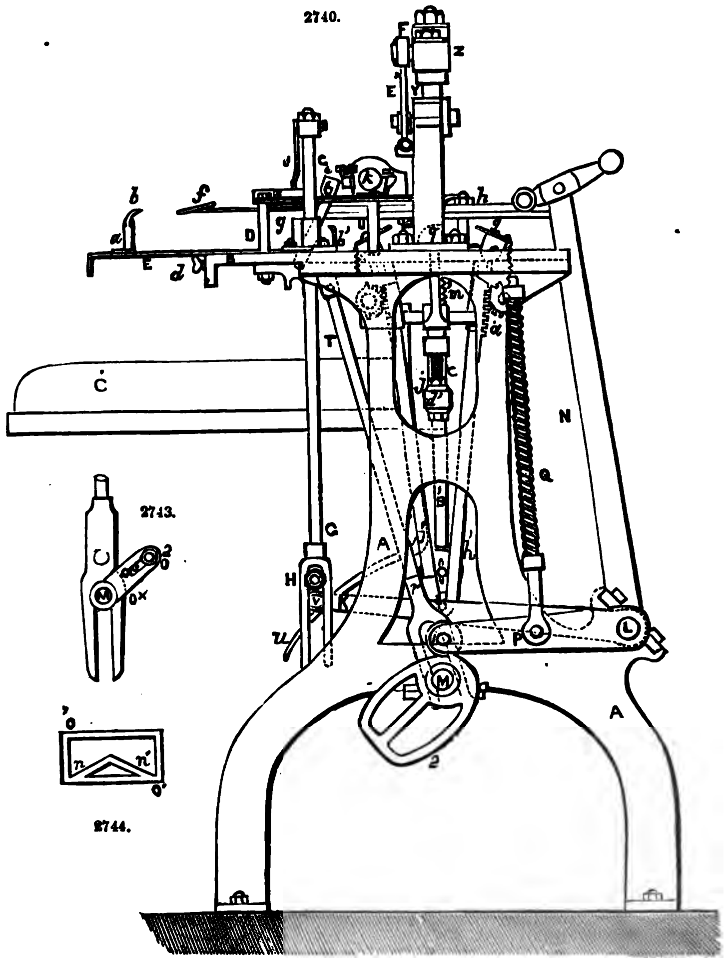


This machine is represented in front elevation at Fig. 2739. Fig. 2740 shows the apparatus in side elevation. Fig. 2741 is a plan, with the upper framing removed, to show more clearly the apparatus for feeding and pressing. A is the main frame of the machine; it carries near its upper part a table B, above which is a plate C supported by columns or pillars D on the table B. The plate C is perforated for the passage of the lifters. The table B also carries near the front end another plate E, free to be moved in and out as required. This plate and a portion of the table B are shown on a larger scale in isometrical view in Fig. 2742, and inside view in Fig. 2746. The envelope blanks are placed on the plate E when drawn out, as shown in Figs. 2740, 2741, and 2746, and are kept in place by projections *a a* on the plate. The projections are fitted at top with bent springs *b b* for a purpose to which we shall presently refer. When the plate E has been sup-

plied with a number of blanks, it is pushed in, as shown in Fig. 2742, until the blanks come against projections *c c* on the table B, when they are in position for being fed singly into the machine. The plate is then secured by means of a thumb-screw *d*.

The table B carries guides F for vertical rods G G which pass through it. These rods are forked at bottom to embrace a horizontal rod H, while at top they are connected by a cross-beam I from which lifters J J depend. These lifters perform the double purpose of gumming the envelope blanks and of lifting them one by one from the supply-plate E. The lifters are forked at bottom, and the forked ends are supplied with gum from the rollers *e e*, which have a to-and-fro motion imparted to them. Immediately after being gummed, the lifters J J fall, come in contact with and take up the uppermost blank, which adheres to their gummed surface. The lifters J J receive up-and-down motion from a rocking lever K centred on a shaft L at back of the machine, and acted

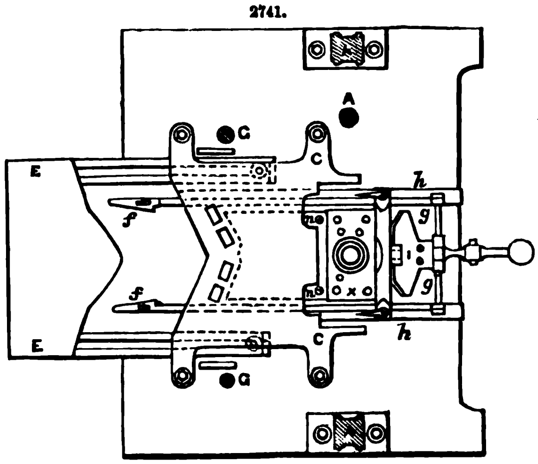
2740.



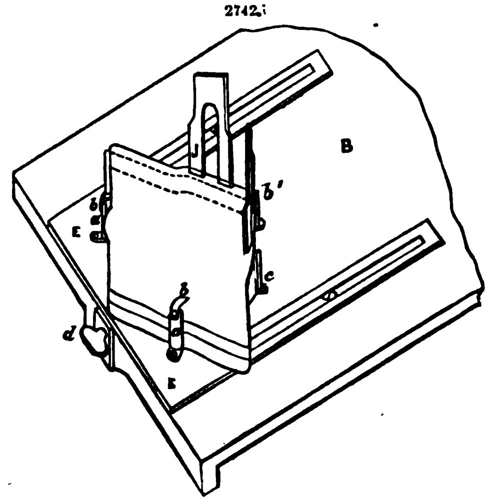
2743.

2744.

2741.



2742.



upon by a cam 1 on the main driving shaft M. This cam is double, that is, it is formed so as to produce a double action; it first raises the lifters J J a certain height (after their forked

ends have been gummed and have taken up a blank), in order that the blank may be released by coming in contact with the under-surface of the plate C. The bent springs *b b* on the projections *a a* of the supply-plate E at the same time bend down or curve the end flaps of the blank to ensure its being caught by fingers. The second portion of the cam 1 then acts to raise the lifters J J still higher, when the gumming rollers *e e* come under their forked ends to supply them with gum for another blank. In the meantime, the first blank has been seized by fingers *f f* on the ends of slide-rods *g g*, which are moved to and fro in a framing *h* fixed on the back part of the table B. This movement is effected by a weighted rod N, which connects a cross-bar O of the slide-rods *g g* to the back shaft L. The weight on the rod N prevents all jar and shock in this part of the machine. The shaft L receives motion from a lever P on its end, acted upon by a cam 2 on the main shaft M. The lever P is furnished with a spring rod Q to keep a roller *i* carried by the lever on the face of the cam. The fingers *f f* are undercut at the back, as seen in Fig. 2740, in order that in their backward motion the undercut portions may come against the blank and carry it to the creasing apparatus.

The gumming rollers *e e* receive their to-and-fro motion by means of levers R R connected to a cross-bar S under the table B; the cross-bar S in its turn receives motion from a nearly vertical rod T, the lower end of which is forked and furnished with a roller *j*, which rides upon and is acted on by a cam 3 on the main shaft M. The gumming rollers *e e* are fitted in a frame which moves to and fro in guides on the plate C; any gum which may fall from the rollers is caught upon this frame. The rollers are composed of printer's composition covered with india-rubber. They receive their supply of gum from another roller or doctor *k*, which rotates partly in a box *l* containing the gum. The doctor *k* is made to rotate by a projection on its axis being acted on by a pin on the shaft U carried by a framing on the table B. This shaft receives motion through a pulley V, over which a band passes to another pulley W on the main shaft M. The gum-box *l* is provided with a scraper or spreader to regulate the supply of gum.

The plate C has two ribs *m m* formed on its under-side, which, as the envelope blank is being carried back by the fingers *f f*, as before explained, keep the end flaps slightly curved downwards, in order that the blank may be presented in that position to the plunger. Beneath the plate C is an inclined plate *n* which supports the body of the blank while being carried to the creasing-box. Immediately the blank is brought over the creasing-box, a top plunger X comes down upon it and drives it into the creasing-box, whereby the four flaps are creased or brought into a vertical position; the plunger X then ascends. Up-and-down motion is imparted to this plunger through a vertical rod Y connected to a horizontal beam Z above the machine. The beam Z is again connected to another vertical rod A^1 forked at its lower end, and carrying a roller *o*, which rides on a cam 4 on the main shaft M, except after the plunger X in its down-stroke has reached the envelope blank. If the pressure of the plunger is not sufficient, greater pressure is caused to be exerted by another roller o^2 which rides over the roller *o* at every revolution of the main shaft. This additional roller o^2 is carried on a pin adjustable in a slot o^3 (see the detached view, Fig. 2743) in an arm or crank o^4 on the main shaft. The beam Z is guided in its motion by a roller which bears against a projection on the upper part of the main frame A.

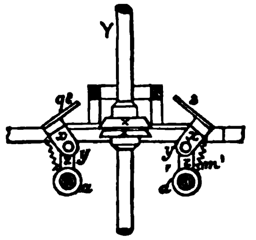
When the top plunger X ascends, two fingers *q q* come down upon and fold the end flaps of the blank; then another finger q^1 comes down upon and folds the back flap, the inner surface of which has been gummed; a fourth finger q^2 then comes down upon and folds the front flap. Simultaneously with the coming down of the two end fingers *q q*, a bottom plunger X^1 is made to ascend to the bottom of the creasing-box to support the blank. Immediately after the folding of the flaps by the four fingers, the top plunger X again descends and carries another blank into the creasing-box. The fingers then retire by means of mechanism we shall presently describe just before the plunger X in its down-stroke would press upon them, and this plunger exerts pressure upon the edges, and still greater pressure upon the gummed portion (owing to the peculiar construction of the face of the plunger) of the envelope, the folding of which has just been completed. The finished envelope and the creased blank are now momentarily held between the two plungers X X^1.

It will thus be seen that each blank remains in the creasing-box during two descents of the top plunger X. The bottom plunger X^1 is made to rise and fall by means of a cam 5 on the main shaft M, against which a roller *r* on a forked vertical rod B^1, which carries the plunger X^1, bears. The finished envelope is caused to fall from the top of the plunger X^1 by means of two projections, which in the down-stroke of this plunger pass through slots, and tilt the back of the envelope, which falls edgewise down a shoot D^1 into a box C^1. The back of this box is free to slide in and out, and is connected to a lever *s*, centred on a support *t* fixed to the main frame A; the pin which connects the lever *s* to the support *t*, also connects to the same support a curved lever *u*. A bar *v*, which supports the vertical rods G G, presses in its downward motion upon the curved portion of the lever *u*, and through the lever *s* causes the back of the box C^1 to carry forward into the box the envelope last delivered from the creasing-box. The box C^1 extends to the front of the machine, and forms a table, which may be used by the attendant while banding the envelopes into packets as they are taken out of the box.

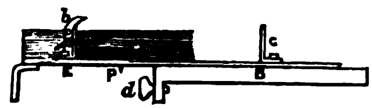
The two fingers *q q*, for folding the end flaps of the envelope, as before explained, are arranged as shown in Fig. 2745, and act as follows;—They each consist of a plate with bevelled edges secured at back to a block *x*, and are furnished with adjusting screws. Each block *x* works upon a pivot *y* in an arm *z*, carrying a boss a^1 formed with teeth on a portion of its periphery; the teeth on each boss are geared into by a rack or toothed boss on the upper part of a vertical rod c^1. The two vertical rods c^1 are connected by a horizontal bar d^1 caused to rise and fall by another vertical rod f^1, the lower end of which is forked and furnished with a roller g^1 which rides over a cam 6 on the main shaft. In the down-stroke of the forked vertical rod f^1 the racks on the rods c^1, by gearing into the toothed bosses a^1, cause the fingers *q q* to turn upon their pivots *y*, and take up a position over the creasing-box and under the top plunger, and so fold the flaps. In the up-stroke

of the rod f^1 the fingers $q\,q$ are caused to retire, and as soon as they are free from the plunger X a spring m^1, connected to the back of each finger-block x, draws down the back of the block, and thereby raises the fore end of the finger.

2745.



2746.



The fingers $q^1\,q^2$ for folding the back and front flaps of the envelope are arranged and act similarly to the fingers $q\,q$, for folding the end flaps, as just explained. The finger q^1 is acted on by a nearly vertical rod h^1 toothed at its upper part and forked at bottom, where it carries a roller i^1, which rides over a cam 7 on the main shaft. The finger q^2 is similarly acted on by a rod j^1, roller l^1, and cam 8. In order that the top plunger X, the second time it acts on each blank, may, after the fingers retire, exert greater pressure on the gummed portion of the envelope, ribs or projections n^1 are formed on the face of the plunger, as shown in Fig. 2744, which is a view of the face of the plunger, to correspond with the gummed portion, in addition to the ordinary rib or projection o^1 on the edges of the face of the plunger. As there are three thicknesses of paper at the gummed portion of the envelope, this portion consequently receives the greatest pressure. The plunger X is perforated for the escape of air. To prevent the envelope blanks adhering to each other, a portion of the supply-plate is removed, as seen at p^1, Fig. 2746, so that the lifters J J, in coming down upon the blanks, may press down and separate their edges.

The forked vertical rods referred to as being fitted with a roller riding on a cam on the main shaft are each furnished with a spring to keep the roller down upon the face of its cam. To raise the top plunger X and its beam Z when necessary for cleaning or repairing the machine, a curved lever E is fitted on the main frame A. By turning the lever on its pivot it comes against a roller F^1 on the beam Z, and raises the beam until the roller falls into a slot formed for the purpose in the lever E^1. See Pin-making Machine.

EPICYCLOIDAL WHEEL. Fr., *Roue épicycloïdal;* Ger., *Epicykloidenrad;* Ital. *Ruota epicicloidale;* Span., *Rueda da epicicloide.*

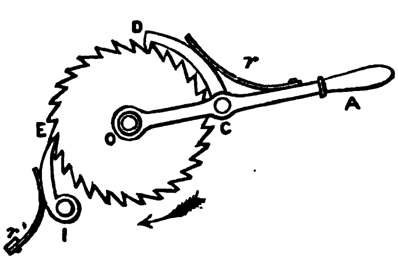
* See Mechanical Movements.

ESCAPEMENT. Fr., *Échappement;* Ger., *Hemmung;* Ital., *Scappamento;* Span., *Escape.*

Escapements are contrivances for converting a reciprocating circular motion into a discontinuous circular motion in one direction.

Fig. 2747 represents an arrangement of this nature. Upon the shaft O is fixed a toothed wheel, the teeth of which form an acute angle, but present one face coinciding with the radius, whilst the other makes with this radius a more or less considerable angle, or, in other words, one face of the tooth is perpendicular to the axis and the other forms a kind of inclined plane. This is called the ratchet-wheel. A lever O A, which moves independently of the shaft, turns upon the same axis O. In a point C of this lever is a ratchet or click C D, the end D of which drops into the teeth of the wheel, and is held in this position by a spring r fixed to the lever. When the lever is moved in the direction of the arrow, it drags the wheel with it, thereby causing the wheel to revolve to a certain extent. When the lever is moved in the contrary direction, the end D of the click slides up the inclined plane formed by the next tooth and drops into the following one, and so on over several teeth in succession. The reciprocating motion of the lever thus causes the shaft to revolve constantly in one direction, but in a discontinuous manner. As the shaft is usually acted upon by a resisting force which would tend to make it revolve in the contrary direction, a contrivance is required to prevent this backward motion. This contrivance is a click, or, as it is commonly called, a pawl I E, which turns about the point I, and drops at its other extremity into the teeth of the wheel; in this position it is held by a spring r' fixed, as well as the axis I, to the frame-work of the machine. When the wheel turns in the direction of the arrow, the inclined faces of the teeth slide over the *pawl* by forcing the spring r' to yield, and in this way a certain number of teeth escape. But when the lever turns in the contrary direction without moving the wheel, this latter is held in its position by the pawl, which cannot yield to the pressure exerted upon it by the tooth, because this pressure normal to the tooth has a direction E N passing between the axes of rotation I and O, and tending to drive the pawl towards the right, which is impossible, since the points O, E, I, are the summits of a triangle the sides of which are invariable.

2747.



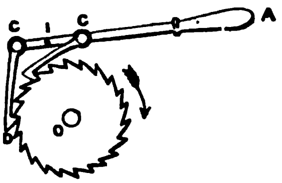
This kind of ratchet is frequently employed in those manual machines which are used to lift the materials in building. It has also been applied with some slight modifications to drags, cranes, presses, &c.

It will be seen that the shaft revolves during one-half only of the oscillation of the lever. But by placing a ratchet at each end of the axis O in such a way that one ascends while the other descends, the motion of the shaft may be rendered nearly continuous. This condition is, however, equally fulfilled by *Lagarousse's lever*, represented in Fig. 2748.

This lever, which turns about a fixed axis I, has two clicks jointed to it in the points C and C'; these clicks fall into the teeth of the wheel O upon the axis of the shaft. They are held in this position by springs fixed to the lever, and the wheel is held by a pawl as in the first arrangement. The way in which Lagarousse's lever works is evident. When the end A is lowered, the click C D drags the wheel round; at the same time the click C' D' is liberated and allows a certain number of teeth to escape successively. When, on the contrary, the end A is raised, the click C' D' drags the wheel round, and the click C D is liberated, allowing, in its turn, a certain number of teeth to escape. In this way the wheel is left stationary only during the very short space of time occupied in changing the direction of the motion of the lever.

In the example, Fig. 2748, the lever acts upon the toothed wheel by *pulling;* it might be made to act upon it by *pushing*, by merely changing the direction of the inclination of the teeth. The shaft, in this case, would turn in the contrary direction.

2748.



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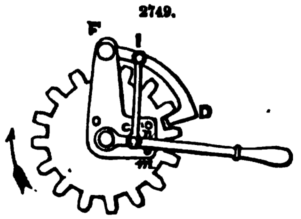

The ratchet-wheels described above are open to the grave objection of causing, when they are large, an intolerable noise, due to the shock of the click each time a wheel escapes. This objection has been removed by the arrangement represented in Fig. 2749. The teeth of the wheel are, in this case, nearly straight, and offer on each side only a slight inclination with respect to the radius. A bent lever F O m n turns about the axis of this wheel independently of the wheel itself. In the point F is fixed a click F D, the end D of which falls into the teeth of the wheel. A lever O A, to the end A of which the force is applied, also turns about the axis O; this lever and the click are connected by the rod C I jointed at its extremities. The play of the lever O A is limited by two pins or studs m and n fixed to the bent lever. When the end A is lowered, the click drops into the teeth of the wheel and forces it round. But when the end A is raised, the click is forced up by the rod C I; and the lever striking against the stud n turns the bent lever independently of the wheel. The end A being now brought back to its former position, the click is drawn down into the teeth of the wheel by the rod I C, and the wheel is again forced round. The stud m merely shows the position of the lever when the click has a firm hold of the teeth. With this arrangement, the intervals of rest are somewhat longer than in those described above.

Instead of the ratchet and toothed wheel, friction may be employed to bring about the same result. Of these contrivances, the two most important are that due to M. Saladin, of Mulhouse, and that known as Dobo's. We will first explain the principle of the former. To that end we will consider, in the first place, a horizontal cylindrical rod or shaft A B, Fig. 2750, revolving between guides, and suppose it embraced by a ring a a', the inner diameter of which is a little greater. This ring is provided with a handle or lever a b, to the end b of which a motive force F may be applied in the plane of the symmetry of the system, which we will suppose to be that of the figure. On account of the play between the shaft and the ring, the latter will slide freely along the shaft when it is held nearly parallel with a right section. But if it is acted upon by a force F which causes it to assume the position shown in the figure, in which it touches the shaft in the two opposite points a and a', sliding may become impossible, independently of the intensity of the motive force. For, in order that the ring may slide along the shaft while maintaining this position, the reactions R and R' exerted by the shaft at the points of contact a and a' must make with the normals a n and a' n' angles equal to the angle ϕ of the friction of the bodies in contact. Let I be the point of intersection of the directions of the forces R and R'. In order that the ring may be moved along with a uniform motion, or in order that it may be on the point of being so moved, equilibrium must exist between the

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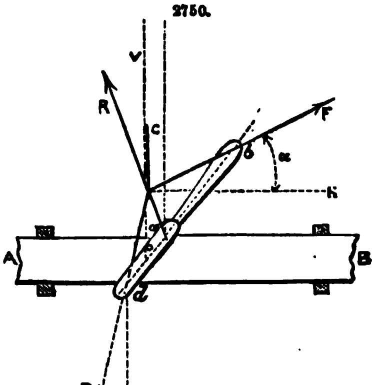
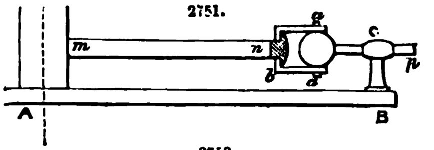


three forces F, R, and R', and consequently the force F must pass through the point I. This condition is sufficient for equilibrium (neglecting the weight of the ring), and to obtain the intensities of the reactions R and R' we have only to transport the force F to I, in a contrary direction, and to decompose it according to the rule of the parallelogram of forces, in the directions a R and a' R'. If now we vary the angle which the reactions make with the corresponding normals, the point of meeting I of these reactions describes a branch of an equilateral hyperbola

a I c which passes through the point a and which has as its asymtote the straight line O V, drawn through the middle O of $a\,a'$ perpendicularly to the direction of the shaft, or to the horizontal I H. This granted, if the force F, passing through the point b, made with I H an angle greater than the angle b I H $= \alpha$, it would meet the hyperbola between I and a; therefore, the reactions, at the point of meeting, must make with the normals angles greater than the angle ϕ, which is impossible. This amounts to saying that, in this case, equilibrium would not exist, and the ring would be forced along the shaft. But if the force F made with the direction of the shaft an angle less than α, its direction would meet the branch of the hyperbola between I and C, and consequently the reactions R and R′ would then make with the normals an angle less than the angle of friction ϕ; and, in this case, sliding becomes impossible. This result is independent, as the student will see, of the intensity of the moving force F. From all this we conclude that, in the case in which the force F makes with the direction of the shaft an angle smaller than α, the ring being unable to slide along the shaft, the latter will be forced in the direction of A towards B, whilst if the angle of F with the shaft is greater than α, the ring may slide without dragging the shaft. Upon this fact, which may be easily verified by experiments, is founded the invention of M. Saladin.

Upon the axis of the shaft is fixed a wheel, the outer rim or fellies of which are broader than the arms or spokes in the direction parallel to the axis of rotation; the section of this rim is shown by the hatched portion of Fig. 2751. It is embraced by a kind of ring formed of the branches $a\,b$, $a\,b$, between which the arm $m\,n$ passes, and a sphere O fixed to the branches $a\,b$, $a\,b$, by a pin through its diameter $a\,a$. This sphere is affixed to a rod p which slides through a hole C in a piece on the end of a lever A B turning about the axis of the wheel, but independent of this wheel. Fig. 2752 shows the general arrangement of the wheel and the lever. In the position there indicated, the rim is seized or pressed between the branches $a\,b$ and the sphere O; it follows from this that when the end B′ of the lever is lowered, the rim is acted upon by a force which tends to make the wheel revolve in the direction of the arrow. When, on the contrary, the end B′ is raised, the end B descending, the branches or arms $a\,b$ assume a position normal to the circumference of the wheel, and may, in virtue of the play left between the circumference and the sphere O, follow the motion of the lever without exerting any force upon the wheel. A similar system $a'\,b'$, on the end of a fixed arm M N, plays the part of the pawl in a ratchet-wheel. When the wheel turns in the direction of the arrow, the branches $a'\,b'$ occupy a position normal to the circumference, and therefore allow the wheel to pass freely. But when the motion is arrested, the branches $a'\,b'$ fall back by their own weight, and if the motion had a tendency to take the direction the contrary of that indicated by the arrow, the circumference of the wheel would be pressed between these branches and the sphere, and the motion would thus be rendered impossible.

2751.



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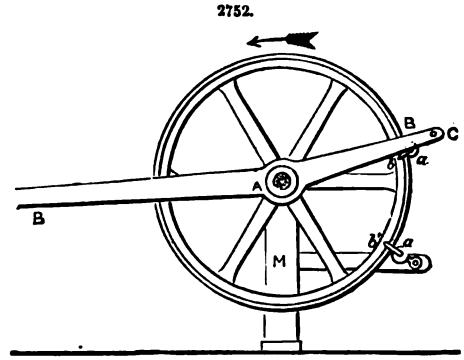

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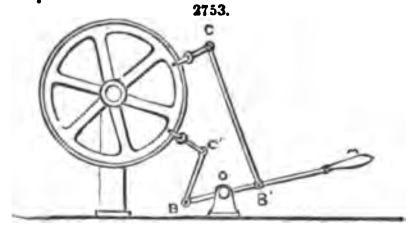
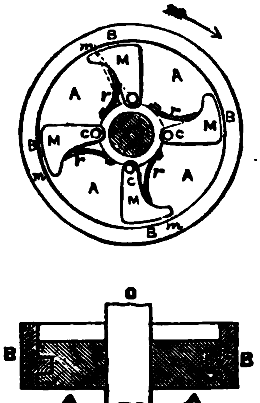


It will be seen that the wheel revolves during one only of the two oscillations of the lever. But a system similar to that of Lagarousse's may be adopted; this arrangement is represented in Fig. 2753. To a lever A B B′, turning about a horizontal axis O, are jointed two rods or arms B C and B′ C′, and to the ends of these C and C′ rings are adapted analogous to those of the system we have been describing; these rings embrace the circumference of a wheel fixed upon the shaft it is required to turn. When the end A of the lever is raised, the point C is raised also; the corresponding ring presses against the circumference of the wheel and causes it to revolve. The point C, on the contrary, is lowered, and the corresponding ring assumes a direction normal to the circumference, allowing the wheel to pass freely. The inverse of this takes place when the point A is lowered, so that the wheel is made to revolve with each movement of the lever.

Dobo's system is founded upon similar principles. A plane and a sectional view is given in Fig. 2754. Upon the shaft O O is fixed a disc A A, revolving with a gentle friction in a ring B B to which the motion is communicated, either by hand on the handles P P, or by some other means. Upon the disc A A in the hollow space between the shaft O O and the ring B B, are fixed a number of pieces M, M, M, turning about axes c, c, c, fixed to the disc, and terminating on the side of the ring in arcs of a circle having a radius a little less than that of the ring. Small springs r, r, r, also fixed to the disc, press lightly upon these pieces; and, as the distance from the axis c to the angle of the piece in contact with the spring is a little greater than the normal distance from the point c to the ring, the effect of the spring is to force this angle to rest against the ring. The normal m O at the point of contact makes only a small angle of about 9 degrees with the straight line $m\,c$. When the ring is turned in the direction contrary to the arrow, the pieces M, M, M, force the

corresponding springs to yield, and, in virtue of the play which is thereby produced, the ring revolves without turning the disc. When, on the contrary, the ring is turned in the direction of the arrow, the springs establish contact between the pieces M, M, M, and the ring; the piece M not being able to turn about the point c in the direction that the ring tends to give it, it follows that the reaction of the ring passes through the point c. But the angle O m c being less than the angle of friction for the substances in contact, the piece M cannot slide with a relative motion upon the ring; consequently, the latter forces the disc, and of course the shaft upon which the disc is fixed, to revolve. The particular advantage offered by Dobo's system is that the extent of the motion communicated to the ring is absolutely arbitrary, instead of being, as in the other systems, limited to the oscillations of a lever.

2754.



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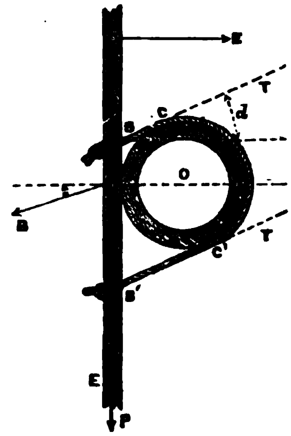


To the foregoing systems may be added that of Chameroy, which is employed in screwing together gas or water pipes. It consists of a cord B C C' B', Fig. 2755, which is passed round the pipe and fixed at each end to a lever D E, the lever being thus pressed against the pipe. If a force F be exerted upon the lever in the direction indicated in the figure, the cord cannot slip over the surface of the pipe, and consequently the pipe is turned upon its axis. If, on the contrary, a force be exerted in the contrary direction, the cord and the lever slip over the surface of the pipe, and may be brought up to their first position. Again applying a force in the direction of F, the pipe is turned upon its axis, and so on till the work is completed.

Viewed mathematically, these results appear as follows:—

Let P be the weight of the lever, T and T' the tensions of the cords B C and B' C', R the reaction of the pipe upon the lever. For the sake of simplicity we will suppose the cords B C and B' C' parallel. Let α be the angle which their direction makes with the horizontal, and i the angle of the reaction R with this same horizontal. The conditions of the equilibrium of the lever D E give the three equations,

$$\begin{gathered} F + (T' + T) \cos. \alpha - R \cos. i = 0, \\ P - (T' + T) \sin. \alpha + R \sin. i = 0, \end{gathered}$$

and, making D A = h and A O = r,

$$F h - P r - (T' - T) r - R r \sin. i = 0.$$

The condition of the slipping of the cord upon the pipe requires $T' = T e^{f\pi}$; putting f for the coefficient of friction, we make $e^{\pi f} = k$, whence $T' = k T$.

The equations of equilibrium thus become

$$\begin{aligned} &F + (k + 1) T \cos. \alpha - R \cos. i = 0, \\ &P - (k + 1) T \sin. \alpha + R \sin. i = 0, \\ \text{and}\quad &F h - P r - (k - 1) T r - R r \sin. i = \\ \text{or}\quad &F \frac{h}{r} - P - (k - 1) T - R \sin. i = 0. \qquad [1] \end{aligned}$$

From the first two we deduce

$$\begin{gathered} F \sin. i + P \cos. i = (k + 1) T \sin. (\alpha - i), \\ F \sin. \alpha + P \cos. \alpha = R \sin. (\alpha - i). \end{gathered}$$

If we deduce from these latter the values of T and of R, and substitute them in [1], we obtain

$$F \frac{h}{r} - P - \frac{k - 1}{k + 1} \cdot \frac{F \sin. i + P \cos. i}{\sin. (\alpha - i)} - \frac{(F \sin. \alpha + P \cos. \alpha) \sin. i}{\sin. (\alpha - i)} = 0,$$

a relation from which, by putting $\frac{k - 1}{k + 1} = m$, we deduce

$$F = \frac{P}{\frac{h}{r} \cdot \frac{\sin. (\alpha - i)}{(m + \sin. \alpha) \cos. i} - \tan. i}. \qquad [2]$$

This formula gives a negative value for F, when α is equal to or less than i. But in the present case i is the angle of the friction of the lever upon the pipe. Therefore, when the common inclination of the cords B C and B' C' becomes equal to or less than the angle of the friction of the lever upon the pipe, we have a result incompatible with the hypothesis, which shows that this

hypothesis is then inadmissible, and that consequently the apparatus cannot slide upon the surface of the pipe.

If the force be exerted in the direction contrary to F, the sign of F must be changed in the formulæ; also, the sliding motion having a tendency to take a contrary direction, we must put $T = T'e\pi$, or $T' = \frac{1}{k}T$, that is, the k must be changed into $\frac{1}{k}$, which is equivalent to changing the sign of m; and, in accordance with the principles relative to friction, the sign of i must be changed. The formula [2] thus becomes

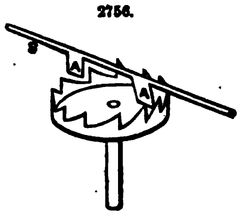
$$F = \frac{P}{\frac{h}{r} \cdot \frac{\sin.(\alpha - i)}{(m - \sin.\alpha)\cos.i} - \tan.i}. \qquad [3]$$

It will be observed that, provided sin. α be less than m, h may be so arranged as to render the denominator positive; therefore the force F is positive in this case. And the result being compatible with the hypothesis of the sliding, it follows that sliding may take place.

The above modes of producing motion is applied to various purposes, among which we may mention *sawing by machinery*, in which case the wood to be sawn has to be pushed forward while the saws ascend; and *weaving by machinery*, where a similar movement of the fabric is required.

Fig. 2756 represents a verge escapement. On oscillating the spindle S, the crown-wheel has an intermittent rotary motion.

2756.



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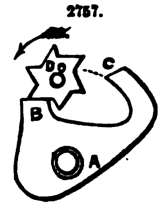

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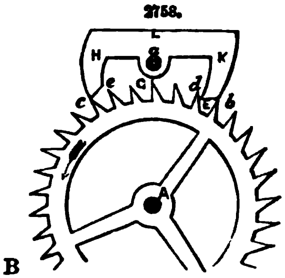


Fig. 2757. An escapement. D is the escape-wheel, and C and B the pallets. A is the axis of the pallets.

Figs. 2758, 2759. The former is what is termed a *recoil*, and the latter a *repose* or *dead-beat* escapement for clocks. The same letters of reference indicate like parts in both. The *anchor* H L K is caused, by the oscillation of the pendulum, to vibrate upon the axis a. Between the two extremities or pallets H K is placed the escape-wheel A, the teeth of which come alternately against the outer surface of the pallet K and inner surface of pallet H. In Fig. 2759 these surfaces are cut to a curve concentric to the axis a; consequently, during the time one of the teeth is against the pallet the wheel remains perfectly at rest; hence the name *repose* or *dead-beat*. In Fig. 2758 the surfaces are of a different form, not necessary to explain, as it can be understood that any form not concentric with the axis a must produce a slight recoil of the wheel during the escape of the tooth, and hence the term *recoil* escapement. On the pallets leaving teeth, at each oscillation of the pendulum, the extremities of teeth slide along the surfaces $c\,e$ and $d\,b$ and give sufficient impulse to pendulum.

2759.

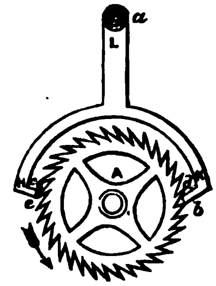
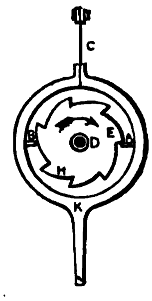


Fig. 2760. Another kind of pendulum escapement.

Fig. 2761. Arnold's chronometer or free escapement, sometimes used in watches. A spring A is fixed or screwed against the plate of the watch at b. To the under-side of this spring is attached a small stop d, against which rest successively the teeth of the escape-wheel B; and on the top of spring is fixed a stud i, holding a lighter and more flexible spring which passes under a hook k at the extremity of A, so that it is free on being depressed, but in rising would lift A. On the axis of the balance is a small stud a, which touches the thin spring at each oscillation of balance-wheel. When the movement is in the direction shown by the arrow, the stud depresses the spring in passing, but on returning raises it and the spring A and stop d, and thus allows one tooth of escape-wheel to pass, letting them fall immediately to arrest the next.

2760.



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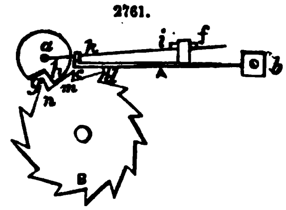


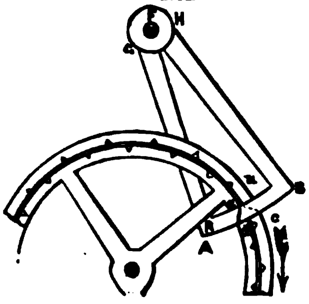
At the same time that this tooth escapes, another strikes against the side of the notch g, and restores to balance-wheel the force lost during a vibration. It will be understood that only at one point is the free movement of balance opposed during an oscillation.

Fig. 2762. Stud escapement, used in large clocks. One pallet B works in front of the wheel, and the other at the back. The studs are arranged in the same manner, and rest alternately upon

the front or back pallet. As the curve of the pallets is an arc described from F, this is a *repose* or *dead-beat* escapement.

Fig. 2763. Duplex escapement, for watches, so called from partaking of the characters of the spur and crown wheel. The axis of balance carries pallet B, which at every oscillation receives an impulse from the crown teeth. In the axis A of balance-wheel is cut a notch into which the teeth round the edge of the wheel successively fall after each one of the crown teeth passes the impulse-pallet B.

2762.



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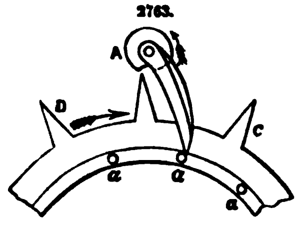

2764.

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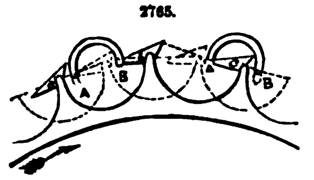
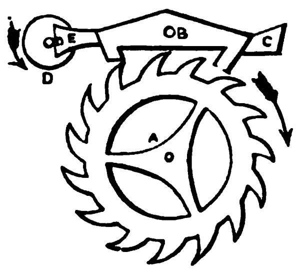


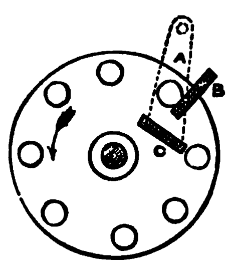
Figs. 2764, 2765. A cylinder escapement. Fig. 2764 shows the cylinder in perspective, and Fig. 2765 shows part of the escape-wheel on a large scale, and represents the different positions taken by cylinder A B during an oscillation. The pallets *a*, *b*, *c*, on the wheel rest alternately on the inside and outside of cylinder. To the top of cylinder is attached the balance-wheel. The wheel pallets are bevelled, so as to keep up the impulse of balance by sliding against the bevelled edge of cylinder.

Fig. 2766. Lever escapement. The anchor or piece B, which carries the pallets, is attached to lever E C, at one end of which is a notch E. On a disc secured on the arbor of balance is fixed a small pin which enters the notch at the middle of each vibration, causing the pallet to enter in and retire from between the teeth of escape-wheel. The wheel gives an impulse to each of the pallets alternately as it leaves a tooth, and the lever gives impulse to the balance-wheel in opposite directions alternately.

2766.



2767.



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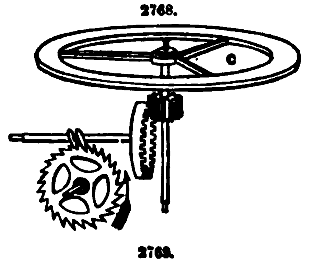

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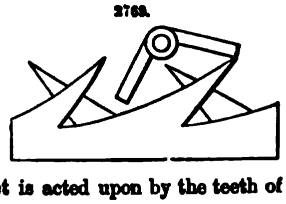


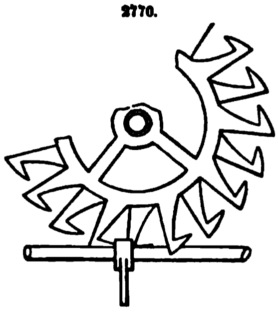
Fig. 2767. An escapement with a lantern-wheel. An arm A carries the two pallets B and C.

Fig. 2768. An old-fashioned watch escapement.

Fig. 2769. An old-fashioned clock escapement.

Figs. 2770, 2771. A clock or watch escapement; Fig. 2770 being a front elevation, and Fig. 2771 a side elevation. The pallet is acted upon by the teeth of one and the other of two escape-wheels alternately.

2770.



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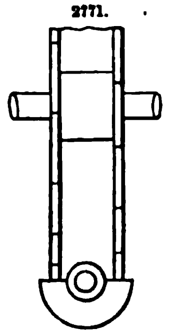

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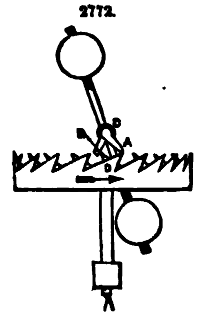
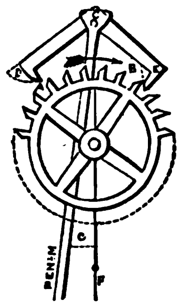


Fig. 2772. Balance-wheel escapement. O is the balance; A B are the pallets and D is the escape-wheel.

Fig. 2773. A dead-beat pendulum escapement. The inner face of the pallet E and outer face of D are concentric with the axis on which the pallets vibrate, and hence there is no recoil.

Fig. 2774. Pin-wheel escapement, somewhat resembling the stud escapement shown by Fig. 2762. The pins A B of the escape-wheel are of two different forms, but the form of those on the right side is the best. One advantage of this kind of escapement is that if one of the pins is damaged it can easily be replaced, whereas if a tooth is damaged the whole wheel is ruined.

2773.



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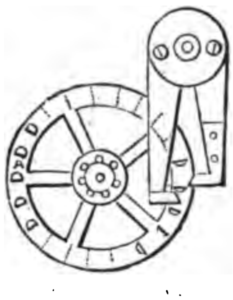

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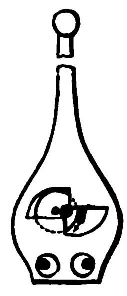
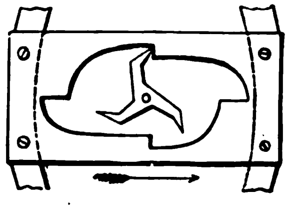


Fig. 2775. A single-pin pendulum escapement. The escape-wheel is a very small disc with single eccentric pin; it makes half a revolution for every beat of the pendulum, giving the impulse on the upright faces of the pallets, the horizontal faces of which are dead ones. This can also be adapted to watches.

Fig. 2776. Three-legged pendulum escapement. The pallets are formed in an opening in a plate attached to the pendulum, and the three teeth of the escape-wheel operate on the upper and lower pallets alternately. One tooth is shown in operation on the upper pallet.

Fig. 2777. A modification of the above, with long stopping teeth D and E. A and B are the pallets.

Fig. 2778. A detached pendulum escapement, leaving the pendulum P free or detached from the escape-wheel, except at the time of receiving the impulse and unlocking the wheel. There is but one pallet I, which receives impulse only during the vibrations of the pendulum to the left. The lever Q locks the escape-wheel until just before the time for giving the impulse, when it is unlocked by the click C attached to the pendulum. As the pendulum returns to the right, the click, which oscillates on a pivot, will be pushed aside by the lever.



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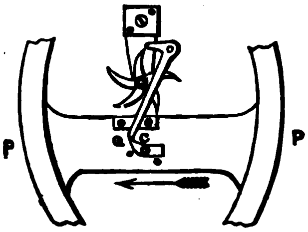

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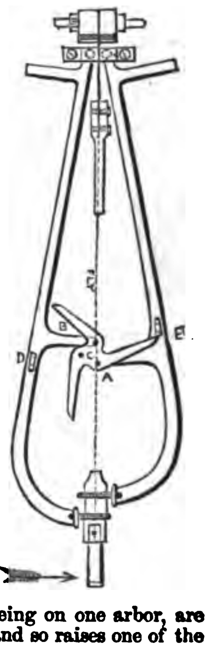

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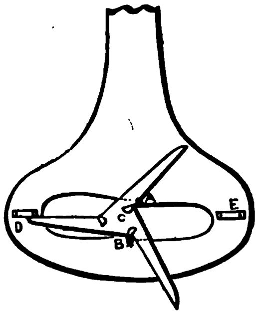


2779.

Fig. 2779. Mudge's gravity escapement. The pallets A B, instead of being on one arbor, are on two, as shown at C. The pendulum plays between the fork-pins P Q, and so raises one of the weighted pallets out of the wheel at each vibration. When the pendulum returns, the pallet falls with it, and the weight of the pallet gives the impulse.

Fig. 2780. Three-legged gravity escapement. The lifting of the pallets A and B is done by the three pins near the centre of the escape-wheel, the pallets vibrating from two centres near the

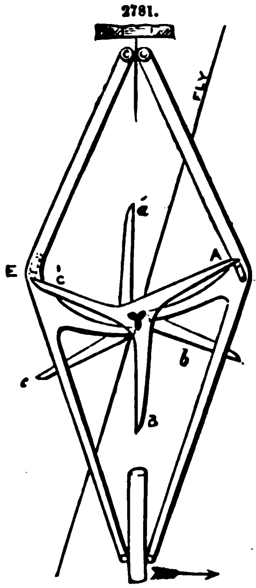
point of suspension of the pendulum. The escape-wheel is locked by means of stops D and E on the pallets.

Fig. 2781. Double three-legged gravity escapement. Two locking wheels A B C and *a b c* are here used with one set of lifting pins between them. The two wheels are set wide enough apart to allow the pallets to lie between them. The teeth of the first-mentioned locking wheel are stopped by a stop-tooth D on one pallet, and those of the other one by a stop-tooth E on the other pallet.

Fig. 2782. Bloxam's gravity escapement. The pallets are lifted alternately by the small wheel, and the stopping is done by the action of the stops A and B on the larger wheel. E and F are the fork-pins which embrace the pendulum.

Fig. 2783. Chronometer escapement, the form now commonly constructed. As the balance rotates in the direction of the arrow, the tooth V, on the verge, presses the passing spring against the lever, pressing aside the lever and removing the detent from the tooth of the escape-wheel. As balance returns, tooth V presses aside and passes spring without moving lever, which then rests against the stop E. P is the only pallet upon which impulse is given.

2781.



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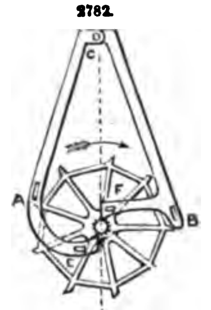

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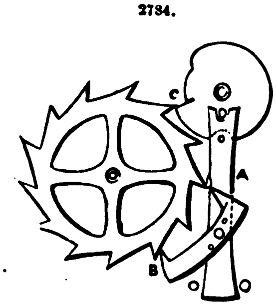

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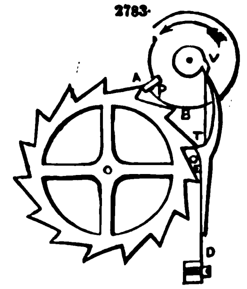

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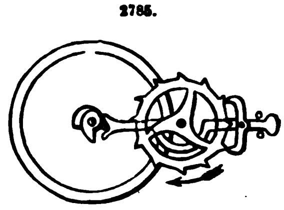
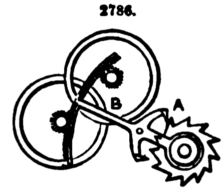


Fig. 2784. Lever chronometer escapement. In this the pallets A B and lever look like those of the lever escapement, Fig. 2766; but these pallets only lock the escape-wheel, having no impulse. Impulse is given by teeth of escape-wheel directly to a pallet C attached to balance.

Fig. 2785. G. P. Reed's patent anchor and lever escapement for watches. The lever is so applied in combination with chronometer escapement, that the whole impulse, balanced in one direction, is transmitted through lever, and the whole impulse in the opposite direction is transmitted directly to chronometer impulse-pallet, locking and unlocking the escape-wheel but once at each impulse given by said wheel.

Fig. 2786. G. O. Guernsey's patent escapement for watches. In this escapement two balance-wheels are employed, carried by the same driving power, but oscillating in opposite directions, for the purpose of counteracting the effect of any sudden jar upon a watch or timepiece. The jar which would accelerate motion of one wheel would retard the motion of other. Anchor A is secured to lever B, having an interior and exterior toothed segment at its end, each one of which gears with the pinion of balance-wheels.

2786.



ESCAPE-VALVE. Fr., *Soupape de trop plein;* Ger., *Flucht Ventil.* See Water-works.

EVAPORATOR PAN. Fr., *Chaudière évaporatoire;* Ger., *Abdampfpfanne;* Ital., *Apparecchio d'evaporazione;* Span., *Cápsula.*

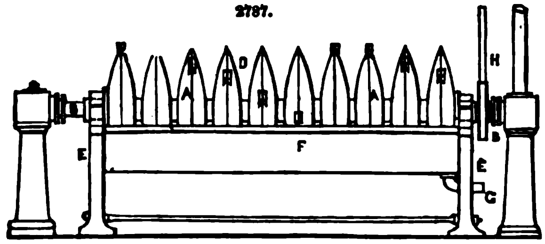
Sugar Evaporating Apparatus.—In concentrating cane-juice, after it has been expressed by the cane-mill, a variety of processes has been adopted; the apparatus most generally in use is called the Battery, and consists of five or six pans all placed in a line, each less than the preceding one in the proportion that the liquor is concentrated. The liquor is first put into the largest pan, and ladled from one to another successively till its arrival at the last, called the finishing teache, in which the sugar is brought to the required density. It is thence taken to the curing house, where it is placed in suitable vessels for allowing the complete drainage of all the molasses or uncrystallizable portion, a large part of which, however, can be rendered into sugar by reboiling, which is mostly effected in refineries.

In the battery process the greatest danger arises near the termination of the boiling in the teaches, under which the fire is immediately placed. The density to which the sugar has been brought renders carbonization difficult to be avoided at this stage of the process, and great care is necessary in the management of the fire.

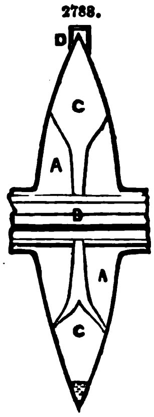
To meet these difficulties, the apparatus, shown in Figs. 2787 to 2789, has been introduced, by which the requisite degree of concentration can be arrived at, without the possibility of applying a temperature injuriously high.

The Bour pan, named after the inventor, and now successfully in operation in many of our sugar-growing colonies, is shown in Figs. 2787 to 2789. It consists of a series of thin hollow discs of copper A A, securely fixed upon a central axis B. The discs are heated and maintained at a uniform temperature by steam, which enters at one end through the hollow axis B. A section of the axis is a cross, Fig. 2789, the edge of each portion having a flange set to one side, forming longitudinal grooves, the use of which is to retain the condensed water from the steam, and deliver it at the extreme end of the axis. The axis is about 9 ft. long, and has fitted upon it ten hollow discs A A, 3 ft. in diameter. In the inside of each disc are two spoons C, fixed to one side of the disc, and running from the centre to the circumference; these collect the water of condensation from the steam, and terminate in tubes, delivering the water into the longitudinal grooves in the axis B. On the outside of the discs are a series of small buckets D, which lift the liquor as the discs move round, and being open at the sides, allow a quantity of it to be distributed in a thin equable film over the entire portion of the surface of each disc that is not immersed in the liquid. This is a feature in the machine that is peculiarly favourable to the liberation of water from the liquor undergoing concentration, when it approaches the density necessary for finish. The axis B is mounted on a frame E carrying a flat shallow pan F, the bottom of which is curved to a radius about 1½ inch longer than that of the discs; into this pan the cane juice is put, after having been evaporated in open pans to 28° or 30° Baume. When the concentration has been carried to the required degree, the remaining liquor is run out of the pan by a valve and pipe G.

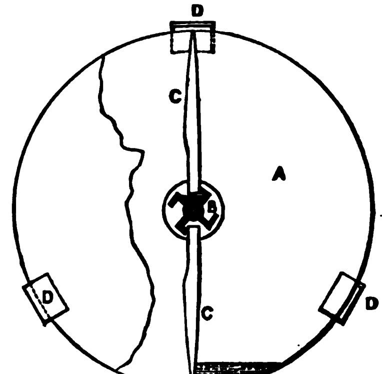
2787.



2788.



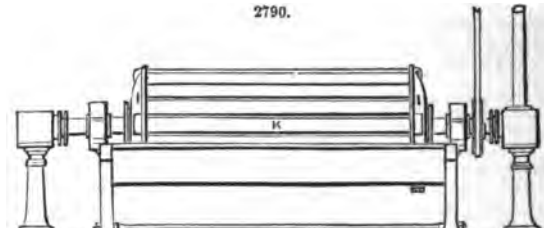
2789.



The discs are made to revolve about ten times a minute, and are driven by a strap and pulley H on the axis B. The exhaust steam from a high-pressure engine is made to enter at one end of the hollow axis at 2 lbs. a square inch pressure above the atmosphere, and the large amount of heating surface which the discs expose for the steam to act upon is the source of the efficiency of the apparatus as an evaporator. The low temperature under which the process is effected, the liquor never exceeding 170° Fahr., renders it peculiarly adapted for the Colonies, where skilled labour is very expensive, and in many places cannot be had.

The adoption of the Bour pan supersedes the use of the teache in the battery, and the granulation of the sugar is finished at a much lower temperature than by the teache, thereby avoiding any tendency to carbonization of the sugar. An apparatus designed for the same object has been previously introduced under the name of the Wetzel pan, so called from its inventor. A side elevation of this apparatus is shown in Fig. 2790. It consists of two hollow discs I I connected by a number of horizontal tubes K; steam is admitted to one of the discs through the hollow axis, and passes through the tubes to the other disc, in which the water of condensation collects and is carried off through the axis at that end. In the use of the Wetzel pan it was found that the crystallization of the sugar is most perfect at the two end discs; and this circumstance led to the adoption in the Bour pan of a series of discs in place of the tubes, whereby the whole apparatus now produces the superior crystals that were previously obtained only from the two end discs.

2790.



EXCAVATION. Fr., *Déblai; Tranchée;* Ger., *Einschnitt;* Ital., *Scavo, Sterro;* Span., *Desmonte.* See Embankment.

EXHAUST-PIPE. Fr., *Tuyau d'échappement à vapeur;* Ger., *Ausströmrohr;* Ital., *Tubo di sfogo;* Span., *Tubo de escape.*

See Details of Engines, p. 1173. Locomotive.

EXPANSION GEAR. Fr., *Mécanisme de distribution de la vapeur;* Ger., *Expansions Steuerung;* Ital., *Congegno d'espansione;* Span., *Regulador.*

See Engines, *Varieties of.*

EXPANSION JOINT. Fr., *Joint glissant;* Ger., *Expansions-röhrenverbindung;* Ital., *Congiunzione a dilatazione libera.*

An *expansion joint* is a pipe so formed as to be compressed endwise by the expansion of the metal by heat.

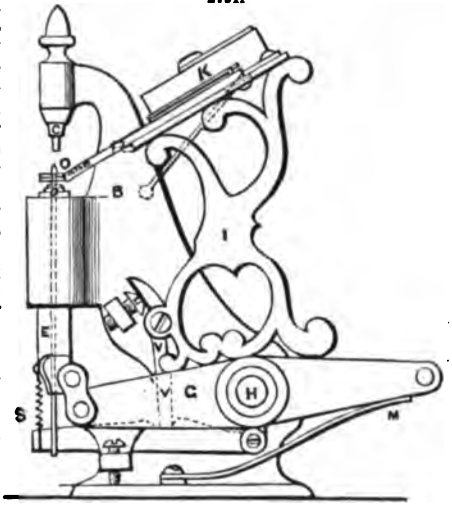
EXPLOSIONS, *Boiler.* Fr., *Explosion des chaudières;* Ger., *Zerspringen oder Platzen der Kessel;* Ital., *Esplosione;* Span., *Esplosiones.*

See Gunpowder.

EYELETTING MACHINE. Fr., *Machine à percer les œillets;* Ger., *Schnürloch Stossmaschine;* Ital., *Macchina da occhiellare;* Span., *Máquina para hacer ojetes.*

The *Eyeletting Machine* of Timothy K. Reed is very complete; it has a hopper K, Fig. 2791, an inclined shoot O leading therefrom, and a striking-up arrangement. The hopper K is cylindrical and placed in an inclined position; within it a brush radiates horizontally from the centre, nearly half-way round the circumference, and, by a rocking movement of the standard I, presses the eyelets through properly-shaped lateral openings in the perimeter directly into the shoot, with their flaring or flange parts down so as to keep the shoot full of them, a spring stop at their lower end preventing their escape. The die, which forms the new flange, is fixed in a socket C, over its end, and beneath the die a pin *o* passes up loosely through an anvil fixed to the frame B, through the lowest eyelet and through the work to be eyeletted. The movement of the lever G elevates the shoot and carries it out of range of the striking-up arrangement, the spring stop yielding in the lateral movement of the shoot. The hopper being connected with the shoot is thus brought to a less inclined position, and the brush within the hopper is rocked by the same movement. When these parts descend, the guide-pin *o* E goes down into its socket.

2791.



FAN. Fr., *Ventilateur, Machine soufflant;* Ger., *Ventilator, Windrad;* Ital., *Ventilatore.*

A *Fan* is an instrument used for producing artificial currents of air, by the wafting or revolving motion of a broad surface symmetrically formed.

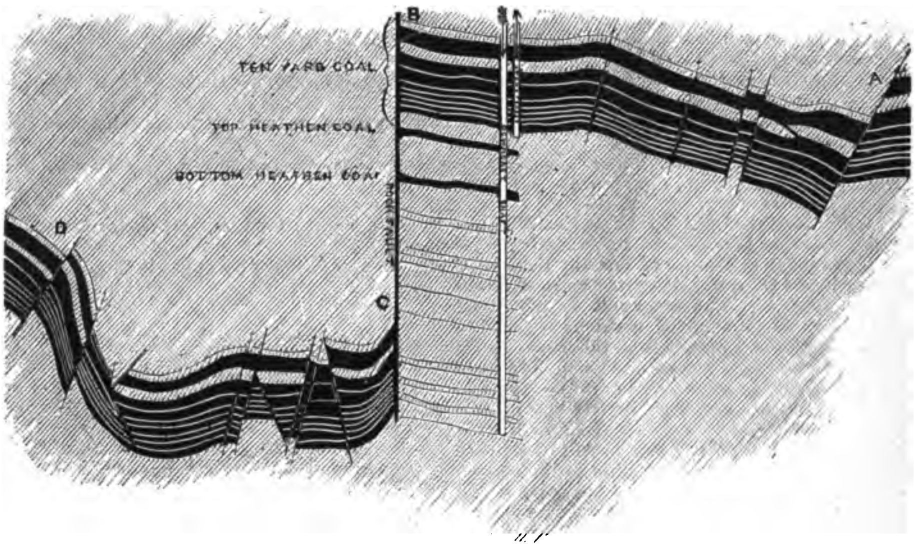
Guibal's Ventilating Fan.—J. S. E. Swindell, in P. I. M. E., states that this ventilating fan is employed for the entire ventilation of the workings of the Homer Hill Colliery, which is situated at Cradley, near Stourbridge, at the south-west of the South Staffordshire coal-field, and consists of about ninety acres of the Thick or Ten-Yard coal. The colliery has been in operation between three and four years, and the plant and machinery are capable of raising 600 tons of coal a day.

The coal seam in that locality is very much cut up by numerous faults, as shown by the section of this colliery in Fig. 2792, which is taken along the line A B C D upon the plans, Figs. 2793, 2794. In the section, Fig. 2792, there is, beginning at the right-hand side, a piece of coal extending 200 yds. distance; then a down-throw at A, bringing the top coal to face the bottom coal; then a length of 380 yds. from A to B, followed by another down-throw of 31 yds. from B to C; then a length of 300 yds., and an up-throw of 15 yds. at D; and still farther to the west two or three smaller faults. These faults, together with numerous fissures, or black things, cause the ventilation of this colliery to require more than ordinary care; and it is from one of these last-named fissures that the gas which caused an unfortunate explosion in this colliery about three years ago is supposed to have issued, having been brought down by the falling roof or shut. Two shafts have been sunk, as shown in the section, Fig. 2792, each 7 ft. 6 in. diameter. The down-cast shaft is carried to a depth of 202 yds. for getting the lower portions of coal lying between the two largest faults; and the upcast shaft is sunk to a depth of only 165 yds. to the upper portion of the coal. A *jackey* pit 19 yds. deep, and an inclined road, connect the lower and upper portions of the seam, and by means of this pit and road the air of the ventilation current returns from the lower workings to the upcast shaft.

Coals are being raised at both shafts in cages having a sectional area in plan of 20 sq. ft., thus leaving for the passage of the air in the shafts by the side of the cages an area of about 24 sq. ft., the total sectional area of each shaft being 44 sq. ft. Previous to the application of the present mechanical ventilation, when the extent of the workings was small, and only natural ventilation from the heat of the workings was used without the aid of a furnace, it was found that the cages acting as pistons in the shafts reversed the current of air every time they ascended or descended;

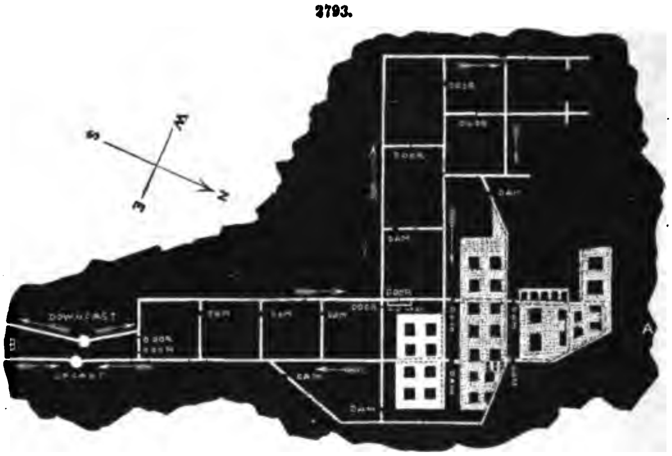
and the consequence was that, if during the time the colliery was standing, say from Saturday until Monday, a quantity of gas had accumulated at the working faces; this had to be driven backwards and forwards, and in fact churned up with the air, until sufficiently diluted to allow of

2792



men entering the workings. This state of circumstances, especially with rapidly extending workings, could not be allowed to go on; and it was consequently suggested by Swindell that a mechanical ventilator should be adopted. As, however, a mechanical ventilator had never been used previously for the Thick coal workings, it had to be considered whether a ventilating furnace would not be better for the purpose but after the question had been thoroughly gone into, it was decided to adopt mechanical ventilation, and the plan of ventilator to be employed had then to be determined

2793.

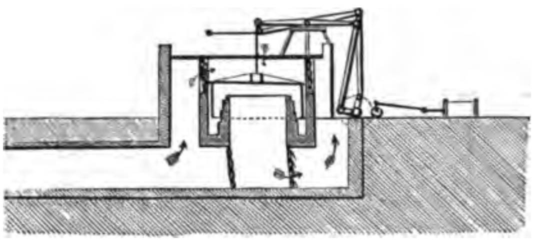


2794.

Amongst the earlier plans for the mechanical ventilation of mines, Struvé's ventilator was introduced in South Wales twenty years ago. It is shown in Fig. 2795, and is a large pump, consisting of a pair of inverted cylindrical vessels like gasholders, each 16 ft. diameter, which are worked up and down alternately with a 6-ft. stroke in annular tanks of water contained within closed chambers. They thus produce the effect of double-acting pumps, drawing in the air from the pit at the top and bottom of each vessel alternately through large inlet flap-valves, and discharging the air so collected at the next stroke through corresponding outlet flap-valves. The

vessels are worked up and down by a pair of beams driven by a steam-engine. This ventilator working at five double strokes, or 60 ft. a minute, delivers 13,000 cub. ft. of air a minute.

2795.



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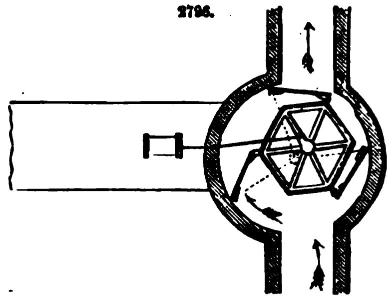
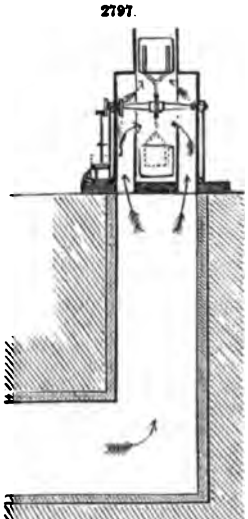


Lemielle's ventilator was used extensively at that time in the collieries of France and Belgium. It is shown in plan in Fig. 2796, and consists of a horizontal hexagonal drum revolving eccentrically within a cylindrical casing, 14 ft. diameter and 7 ft. deep, and carrying three vanes, which are made to open and close during each revolution by eccentric arms, like a feathering paddle-wheel; the drum works close against one side of the casing, giving a passage for the air on the opposite side only. By the rotation of the drum, therefore, the air is drawn in at one side of the casing and discharged at the other side, in a manner similar to the passage of the steam in some forms of rotary engines. This ventilator working at twenty-one revolutions a minute delivered 16,000 cub. ft. of air a minute, with a vacuum of 0·8 in. water-gauge, the velocity of the tips of the vanes being 900 ft. a minute.

The simplest form of mechanical ventilator was Nasmyth's ventilating fan. This ventilator, Figs. 2797, 2798, consists of a simple fan with eight radial vanes, 13½ ft. diameter and 3½ ft. width, driven direct by a small vertical steam-engine coupled to a crank on the end of the fan shaft. The fan works within a casing enclosed only at the two sides and entirely open round the circumference; and it draws the air in at the centre on each side. It ran at a speed of sixty revolutions a minute, or 2500 ft. a minute velocity of the circumference, and delivered 45,000 cub. ft. of air a minute; the lineal velocity of the air-current in the upcast shaft was 800 ft. a minute, with a vacuum of 0·5 in. water-gauge.

2797.



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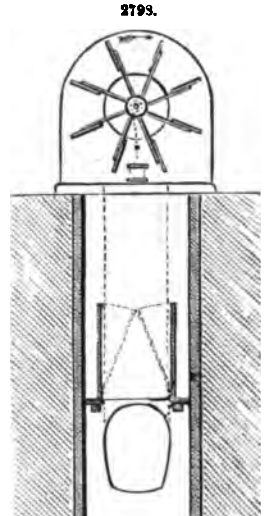


The two mechanical ventilators first referred to involve a complication of construction and a consequent risk of accidental derangement and stoppage, which form a serious objection to the introduction of mechanical ventilation in the place of furnace ventilation; but the fan ventilator, says Swindell, is so simple, compact, and substantial in its construction, as to be free from this objection.

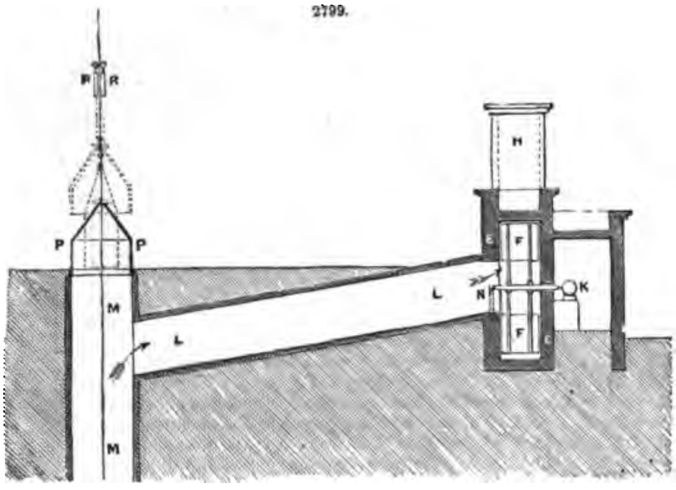
The Guibal fan is represented in working order in Figs. 2799, 2800; Fig. 2799 being a longitudinal section, and Fig. 2800 a side elevation.

The ventilating fan F is 16 ft. 6 in. diameter and 4 ft. 9 in. wide, and is driven by a horizontal steam-engine K, Fig. 2799, coupled direct to a crank on the shaft of the fan. The engine is shown in plan, Fig. 2801; it has a 10-in. cylinder with 16 in. stroke, and is made of simple construction, very strong and durable. The steam for working the engine is supplied from the winding-engine boilers at 50 yds. distance, by a 3-in. pipe laid in sand underground, the pressure of steam being 40 lbs. a square inch.

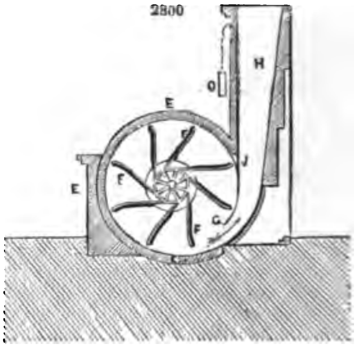
The ventilator consists of an outer casing of brickwork E, Figs. 2799, 2800, the rotating fan F, an adjustable shutter G at the discharge orifice, and an outlet chimney H. The casing E is a ring of brickwork 14 in. thick, about two-thirds of the circumference being a circle concentric with the fan, and the remaining portion eccentric and with a larger radius, so as to enlarge the casing gradually towards the point of discharge. The upper portion of the arch springs from a cast-iron girder J, Fig. 2800, which extends across the opening into the chimney, and is formed of a wedge-shaped section to connect the two lines of brickwork. The side of the chimney, which forms the continuation of the bottom of the casing, is carried up inclining outwards, thus gradually increasing the sectional area of passage up to the top; the other three sides of the chimney being vertical, Figs. 2799, 2800. The sides of the fan-casing E are closed by vertical walls of brickwork 20 in.

thick; and a circular opening 6 ft. 7 in. diameter is made in the centre of one side for admitting the air from the mine to the fan. This opening is connected by a drift L with the upcast shaft M; the drift is 35½ sq. ft. in sectional area and 43 ft. long.

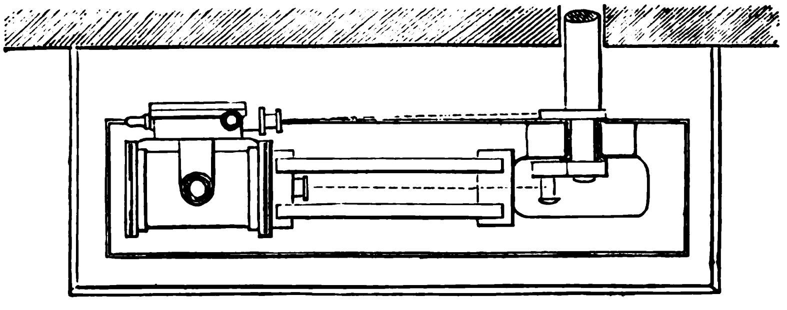
2799.



2800



2801.



The centre framing of the fan consists of two cast-iron octagonal centres 4 ft. 7 in. diameter, which are keyed upon the main shaft made of wrought iron 7 in. diameter; and on each of the eight sides of these castings is bolted a wrought-iron arm made of a flat bar 3½ in. by ¾ in.; these arms are bolted together where they cross one another, so as to form a strong and light frame. The eight vanes of the fan are made of 1¼ in. deal, bolted to angle-irons that are riveted upon the wrought-iron arms; the vanes are each 4 ft. 9 in. wide and 5 ft. 7 in. long, giving an area of 26 sq. ft., and they work with 1 in. clearance at each edge from the side walls and 2 in. clearance from the circumference. Each vane is inclined backwards through the inner half of its length at an angle of 45° from the radial direction; and the outer half is curved forwards to the extent of 10 in. at the end. The inner ends of the vanes extend to 3 ft. 2 in. distance from the centre, the clear space in the centre being about ⅓ of the diameter of the fan. The outer end of the fan-shaft works in a carriage fixed upon a cast-iron girder N, which extends across the inlet opening in the side wall of the fan-casing E; and the inner end of the shaft is carried upon the engine-bed, Figs. 2799 and 2801. When the fan is running at its usual working speed of twenty-six revolutions a minute, the outer ends of the vanes move at the speed of 1350 ft. a minute, but the speed of the engine-piston at the same time is only 70 ft. a minute.

The adjustable sliding shutter G, Fig. 2800, at the outlet side of the fan-casing, is made of 1¼-in. deal boards similar to those of the vanes of the fan, sliding in cast-iron grooves that are built into the side walls; these grooves are made to the same circle as the upper part of the fan-casing, with the same clearance from the tips of the vanes. The boards forming the sliding shutter are bolted to flexible strips of hoop iron, so as to allow of their freely following the curved groove; and the shutter can be raised or lowered as desired by means of a chain passing over a pulley near the top of the outlet chimney, with a balance-weight O, Fig. 2800, the upper end of the shutter sliding up within the chimney. This adjustable shutter is used in the varying conditions of the underground workings, for securing the most effective results from the fan by adjusting from time to time the area of discharge-opening in accordance with the quantity of air to be discharged at any time. The opening of the outlet chimney is 3 ft. 3 in. by 4 ft. 11 in. at the bottom, and increases to 6 ft. by 4 ft. 11 in. at the top, giving an area of discharge of 29·4 sq. ft. The total height of the chimney is 32 ft. from the bottom of the fan.

In applying the ventilating fan at the colliery, an arrangement had to be made for covering the

top of the upcast shaft, in order to prevent the air from being drawn in by the ventilator at the top of the shaft instead of from the workings below. There were two ways of doing this; either to enclose and cover a sufficient extent of ground round the shaft for allowing the tubs to be changed within closed doors; or to have a movable cover over the shaft, to be raised like the ordinary fence at the mouth of the shaft every time the cage ascended. The latter method was adopted as the simplest and most convenient, and it has been found to answer every purpose. The movable cover of the shaft, as shown in Fig. 2799, consists of a rectangular wood box P, about 6 ft. square and 8 ft. 6 in. high, upon which is a pointed roof with a hole 8 in. square at the top for the winding rope to work through; and this hole is covered with a loose sliding piece of wood, through which the rope works in a close-fitting hole, so that every time the rope oscillates laterally this sliding piece moves freely with it in any direction, without uncovering the larger hole. The movable cover is connected to two balance-weights R by chains passing over pulleys fixed at the top of the conductors; and the cage every time it reaches the top of the shaft raises the cover, as shown by the dotted lines in Fig. 2799, the strain being relieved from the winding rope by the balance-weights, so that the cover as now balanced is not so heavy on the rope as the ordinary fence at the other shaft.

The course of the current of air in the workings of the colliery is shown by the arrows on the plans, Figs. 2793, 2794. The current passes from the downcast shaft to the first split at a depth of 165 yds., where the greater portion passes along the gate roads for a distance of 810 yds. in the upper workings, returning by the gate roads and air-head for 500 yds. distance to the upcast shaft. The remaining portion of the in-going air descends to the second split at a depth of 202 yds., and passes along the gate roads 530 yds. to the lower workings, returning by the gate roads and jackey-pit and air-head, 710 yds. distance to the upcast shaft. Here it joins the return air from the first split; and the whole quantity of air passes into the ventilating fan through the inclined drift L, Fig. 2799, of 43 ft. length, which goes off from the upcast shaft at 6 ft. depth below the surface.

The fan is kept running in ordinary working at about twenty-six revolutions a minute, at which speed 13,600 cub. ft. of air a minute pass into the ventilator with a vacuum of 0·15 in. water-gauge. This supply of air is found to keep the workings well ventilated, their average temperature being only 54°, and only 60° in the hottest portion of the workings even when the temperature was 75° at the top of the downcast shaft on the hottest day observed. The fan can be got up to full speed from standing, in only about one minute's time. At the speed of sixty-five revolutions a minute, 37,500 cub. ft. of air a minute pass into the ventilator, with a vacuum of 1·02 in. water-gauge and at the extreme speed of ninety-six revolutions a minute, 51,700 cub. ft. a minute pass into the ventilator, with a vacuum of 1·75 in. water-gauge.

When the ventilator is standing still with the adjusting shutter wide open, about 9130 cub. ft. of air a minute pass through it from the natural current of ventilation due to the heat of the workings. When the ventilator is stopped after running at twenty-six revolutions a minute, and delivering 13,600 cub. ft. of air a minute, the quantity of air passing through it in the sixth minute after stopping is 4260 cub. ft., and in the sixteenth minute 4080 cub. ft., the adjusting shutter in this case being only half open. When it is stopped after running at sixty-five revolutions a minute, and delivering 37,500 cub. ft. a minute, the air passing through it in the sixth minute afterwards is 4790 cub. ft., and in the sixteenth minute 4400 cub. ft., the shutter being half open.

The lifting of the cover at the top of the upcast shaft, and the passage of the *cages* in the two shafts, affect the vacuum in the fan drift in the following manner, as shown by the *water-gauge* placed about midway in the drift, when the fan is running at about sixty-five revolutions a minute.

	Water-Gauge.
Cover open and cage empty	0·95 in.
Cover closed and cage standing still	1·10 „
Cover closed and cage beginning to descend in upcast shaft	1·25 „
Both cages half-way in the two shafts	1·45 „
Cage reaches bottom of upcast shaft	1·15 „
Cage ascending in upcast shaft	1·05 „
Both cages half-way	1·00 „
Cage at top of upcast shaft and empty, and cover open as at first	0·95 „

Whilst the cover is open at the top of the upcast shaft during the changing of the tubs, $\frac{1}{18}$ of the total quantity of air passing into the ventilator is drawn in direct from the surface through the open top of the shaft, occasioning a momentary loss of that amount in the ventilation of the workings. This occurs about once every minute when the pit is in full work, and the cover remains open for about six seconds each time, or $\frac{1}{10}$ of the whole time of working. The total loss of air from the uncovering of the pit top amounts consequently to less than $\frac{1}{10}$ of the whole work of the ventilating fan.

One object in the design of the Guibal ventilating fan is to discharge the air into the atmosphere with as low a final velocity as possible; because whatever excess of velocity there is in the discharged air beyond the velocity of the ascending current in the shaft is an absolute waste of power. The ascent of air in the shaft at the Homer Hill Colliery being 13,600 cub. ft. a minute with the ventilator running at twenty-six revolutions a minute, and the sectional area of the shaft being 44·2 sq. ft., the velocity of the current of air in the shaft is about 300 lineal ft. a minute. The velocity of the air in rotation at the circumference of the fan at the above speed of twenty-six revolutions a minute is 1350 ft. a minute, or $4\frac{1}{2}$ times the velocity of the ascending current in the shaft; but the area of the orifice of the outlet chimney being 29·5 sq. ft., the air cannot have a greater velocity at its exit, if it fills the outlet chimney, than 460 ft. a minute, or only $1\frac{1}{2}$ times the velocity of the current in the shaft. The surplus moving power in the quicker moving air

at the extremities of the fan arms is therefore restored by the retarding of the current at the outlet, instead of being lost, as would have been the case if the fan had discharged direct into the air round its whole circumference.

Another object in this ventilator is to obtain the maximum useful effect of the fan under each of the varying circumstances under which it has to work in order to meet the requirements of the mine ventilation; because the fan can only work to the best advantage with the exact area of discharge opening that is suited to the quantity of air to be discharged in each case, and the resisting pressure at that particular time. If the discharge opening is too large, a back current into the fan from the upper part of the discharge opening is produced, causing a waste of power by putting useless air into motion; and if, on the other hand, the discharge opening is too small, an unnecessary resistance to the discharge of the air is produced, with a consequent waste of power.

The following case that occurred at the Homer Hill Colliery will illustrate the facility with which the ventilator can be immediately adapted to any alteration in the requirements of the ventilation. A length of about 70 yds. of gate road having been cut off from the course of ventilation, it soon became filled with gas; and in order to remove the accumulation of gas, and allow the men to enter this portion of the workings, a dam sheet was put across the in-going airway, just beyond the entrance to the gate road that had to be cleared of gas, thereby partially stopping the passage of the air-current; and an air-pipe was carried from the entrance of the gate road through a fixed dam into the return air-passage. The ventilator was then set running at double speed, about sixty revolutions a minute, thus maintaining the ordinary ventilation of the pit by drawing the same quantity of air past the sides and bottom of the dam sheet as had previously, with the ordinary speed of twenty-six revolutions a minute, been passing through the unobstructed airway before the dam sheet was put up. The remaining portion of the air being forced into the gate road that was charged with gas, began immediately to drive the gas forward through the air-pipe, and the gas was cleared from the gate road as fast as the air-pipe could be extended along it from the entrance by laying down additional lengths of pipe; the whole of the accumulation of gas was thus cleared out in the course of a few minutes throughout the entire distance, without interfering with the regular ventilation of the pit.

In the use of the ventilating fan, as the ventilation of the pit is dependent upon the continuous working of a piece of machinery, it has been contemplated to provide by the erection of a duplicate engine and fan against any accident happening to the machinery; but the construction of the engine and fan is so simple and durable, and the wear and tear so slight in consequence of the very moderate speed of working, that no such provision of duplicates has yet been made in any instance; and in the writer's opinion it is only in the case of a fiery mine that any such provision will really be required. The liability of the ventilator to get out of order is exceedingly small; and no accidents of any consequence to the maintenance of the ventilation have yet occurred with any of the fourteen ventilators now (1869) at work at different mines, some of which are as large as 30 ft. diameter and 10 ft. width, and capable of delivering 100,000 cub. ft. of air per minute with a vacuum of 3 in. column of water.

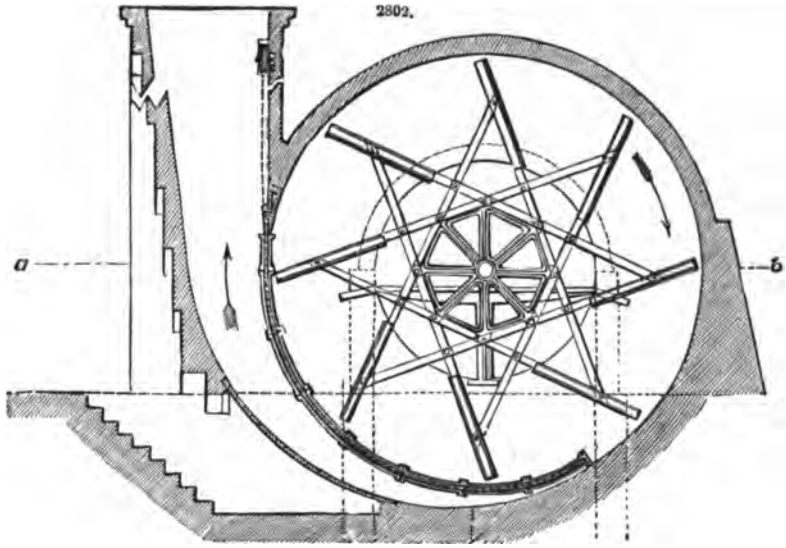
At Pelton Colliery, in Durham, where one of the Guibal ventilators has replaced a ventilating furnace, the following is the comparison of the two modes of ventilation. The depth is 180 yds., and with the furnace the average temperature was 235° in the upcast shaft, the quantity of air circulated 48,000 cub. ft. per minute, and the vacuum 0·9 in. water-gauge; and the consumption of coals was 90 tons per fortnight. With the fan the consumption was 60 tons per fortnight, with nearly double the quantity of air supplied, or 82,370 cub. ft. per minute, and a vacuum more than double, or 2·15 in. *water-gauge*. In order to obtain such an increased volume of air with the furnace ventilation, so high a temperature would have been required in the upcast shaft as probably to be impracticable; and the consumption of coals would have been increased to about 290 tons a fortnight, instead of the 60 tons consumed by the fan for the same work.

Thus where the fan has replaced the furnace, it has been proved by actual comparison that the economy of coal resulting from the change is very great. If, indeed, fuel were the only consideration, there would no doubt be a certain depth of shaft, combined with other conditions, at which a given quantity of coal could be burnt in a furnace so as to produce a current of ventilation equal to that produced by the consumption of the same quantity of coal in raising steam for working a ventilating fan. Such a depth, however, could not be less than 400 yds., and would involve an extraordinary high temperature in the upcast shaft with the furnace ventilation. The presence of cast-iron tubbing in the upcast shaft, even though protected with fire-brick, and also of pump or steam pipes, is a very serious objection to the adoption of a furnace; and when the upcast shaft is a working shaft, the wear and tear becomes very great, and the heat and smoke from the furnace render the shaft almost useless for men to work in. In the case of the Homer Hill Colliery it is estimated by Swindell that to produce a current of 45,000 cub. ft. a minute, with a vacuum of 1 in. water-gauge, an average temperature of about 150° would be required in the upcast shaft if a furnace were employed.

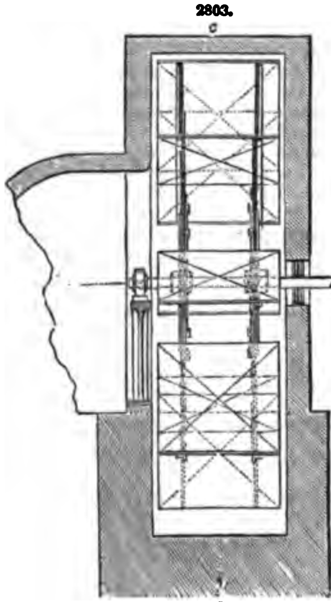
With respect to the ventilator of Guibal, the following comparisons were made by W. Cochrane, and printed in the Transactions of the North of England I. M. E., 1865:—

The ventilator employed by Cochrane is illustrated in detail by Figs. 2802 to 2807. This fan also consists of eight vanes, each of which is formed of 1½-in. oak cleading, secured by bolts to a pair of bars and angle-irons, which are bolted to two cast-iron octagonal bosses keyed on the main shaft. These bars being carried past the boss and interlaced, as shown in the accompanying drawing, form a very firm structure, at the same time simple and inexpensive, admitting of a speed of as much as one hundred and fifty or two hundred revolutions a minute, without any danger. This is an important improvement in construction; which improvement will be seen from Atkinson's paper upon the Elsecar Fan, of which we shall speak presently.

2802.



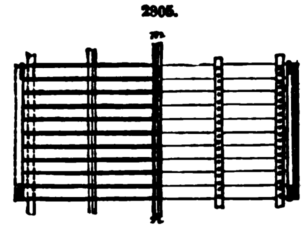
2803.



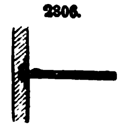
d

Section following the line e f.

2805.

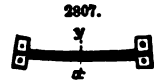


2806.



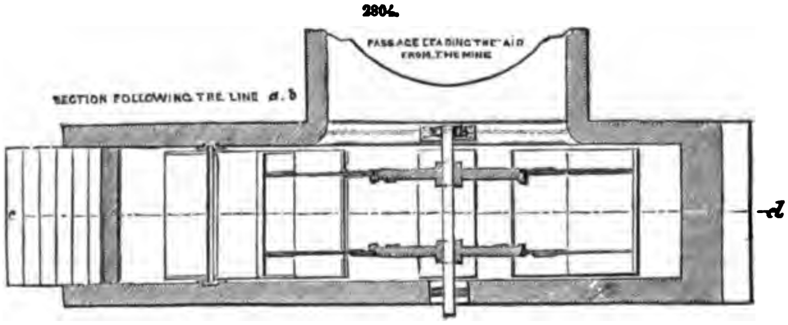
Section following the line x y.

2807.



Section following the line m n.

2804.



The outside diameter of the vanes is 23 ft., the width 6 ft. $6\frac{3}{4}$ in., and each vane extends about 8 ft. into the interior of the fan, being inclined at an angle of *sixty-seven and a half degrees* to a radial line through the apex of the octagonal boss.

The main shaft is driven by a vertical direct-acting engine, with cylinder $23\frac{5}{8}$ in. internal diameter, and $19\frac{11}{16}$ in. stroke, worked at high pressure.

A wall is built on each side of the fan, giving about 1 in. clearance to the side of the vanes. Outside of one wall the engine is fixed, and in the other an inlet orifice of proper size is left, such inlet being connected with the upcast shaft. An arch is carried over the fan, giving about 2 in. clearance to the vanes, and in continuation of this arch an invert to a point about one-eighth of the circumference below the centre line, at which point the 2 in. clearance is increased gradually, expanding the lower curve of the casing till it ends in the sloping side of a chimney formed between the continuation of the side walls of the fan-erection; see Fig. 2802. A sliding shutter is fitted into cast-iron grooved rails for about one-fifth of the circumference, which enables the concentric circle of the top arch to be completed nearly round the fan—that is, giving the 2 in. clearance to the vanes. This shutter is worked by a chain passing over *sheaves* at the top of the chimney and to the outside. For convenience, a manhole-door is left at the foot of the sloping side of the chimney.

The fan being set in motion, the air is drawn through the inlet from the mine, and discharged below the shutter into the chimney, from the top of which it is seen to issue at no great velocity.

The theory and practice of exhausting fans having hitherto been, that there should exist a free discharge all round the circumference, this is the first application to mining ventilation of an exhausting fan which is covered in as described, and in the complete arrangement of which are found the requisite correctives of such a covering, which, without them, would still offer only a very ineffective machine. By the covering, the opposing action of winds is prevented, which is a serious check to fans discharging all round the periphery; but the object of chief importance is to prevent the communication of motion by the revolving vanes to the surrounding exterior air, and the formation of currents, which, in an open-running fan, creep along the sides and vanes from the exterior air to supply the partial vacuum caused in the interior by the revolution of the fan; the demonstration of these facts was well seen in an open-running fan at the Tursdale Colliery, county of Durham. A sensible diminution of the ventilating current was perceived in this fan, with a wind from the N. or S., the direction in which the fan discharged; in one instance, with a high south wind, reducing the air-current one-third of its usual quantity with a calm atmosphere. The air-currents from the exterior at all times could be distinctly seen entering the fan by the drawing in with them of the exhaust steam, which was at that time allowed to discharge from the fan engine at the level of the top of the fan. In consequence of Guibal's system being thoroughly and satisfactorily tested in Belgium, it was resolved to adopt the covering and chimney to the Tursdale fan, which was done, but only temporarily in wood, the joints being made as nearly air-tight as possible in the covering, but not in the chimney. The improvement will be seen on comparing the following results:—

	Revolutions a minute.	Cubic Feet of Air a minute.	Water-Gauge.	Steam-Pressure at Cylinder.	Coal consumed in 24 hours.
Open running—May, 1862 ..	50	22,170	·55	25 lbs.	5 tons.
Covered in—October, 1862 ..	50	32,930	90	25 lbs.	4 tons.

while the power utilized was found to be increased from 12·69 per cent. when open running, to 26·3 per cent. when adapted as above described.

Thus a heavy loss by the entry of exterior air into the open-running fan is evident. On the other hand, with the casing and other appliances of the Guibal system, the space outside the vanes, that is between their extremities and the inside of the casing, presents an aid to the ventilating power, instead of a source of loss. Contrary to what might be expected, and contrary to theory (for the air is thrown off the extremities of the vanes against the casing), a partial vacuum is found in this space, the amount of which, at various speeds, will be seen from the annexed tabulated results of experiments. But the covering in of the fan alone would produce the following disadvantages;—it would check the free discharge of the air, and would communicate to it a high velocity—hence the adaptation of the other parts, namely;—

The shutter and chimney, which are the other new elements in this system. By means of the shutter enlarging or diminishing the outlet, the volume of air drawn by the fan can be so regulated as to suit the special requirements of the mine, and produce the greatest economical effect. By no known theory can the quantity of air be determined which such a ventilating machine will draw from any particular mine; hence the necessity of experimental trials to determine the best size of outlet and the easy means employed for this purpose. If the outlet be too large, air will be drawn back into the fan, as is the case with open-running fans, and in this also if the shutter is imperfectly adjusted. If the outlet be too small, the air cannot get quickly enough away. In either case, economical effect is lost; and as the circumstances of a mine are never long the same, it seems evident that a machine incapable of such an adjustment must be defective.

The following experiment upon the Elswick Fan to fix the position of the shutter shows the results above mentioned.

Calling the lowest position of the shutter zero, and the highest 1, the intermediate positions will be expressed fractionally;—

	No. of Revolutions a minute.	Water-Gauge near Inlet.	Position of Shutter.	Remarks.
a	55	1·150	1	Steam-pressure 32 lbs. constant, and valve not altered.
b	60	·350	0	
c	55	·800	½	
d	52	1·040	¾	
e	55	1·100	¾	Steam increased in quantity to get 55 revolutions.
f	52	1·085	⅞	Steam as at *e*.
g	55	1·180	⅞	Steam increased in quantity to get 55 revolutions.

The position of ⅞ was fixed as the best for these conditions.

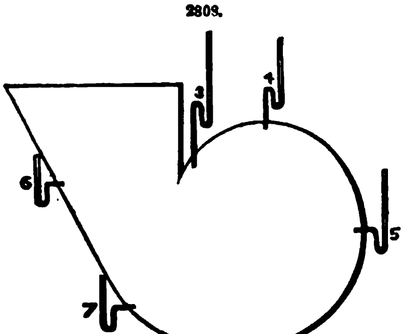
The chimney contributes also greatly to the useful effect, being shaped for this special object —the sectional area increasing upwards. This enables the air which is discharged under the shutter at a high velocity to expand, and, spending its force in the chimney, to pass out at a very low velocity, thus benefiting the ventilating power to the extent of this difference. It is true that the high velocity of discharge absorbs a corresponding amount of the power applied to the fan, but the attainment of the partial vacuum in the interior of the fan, due to the centrifugal force of the vanes in the first instance, must impart to the discharged air their velocity, and it is to restore some portion of this power and make it useful for the ventilating effect that the chimney is arranged. From the following Table of results the depression of the water-gauge will be noticed in the positions, Nos. 3, 4, 5, and 7, the three first being fixed into the space between the vanes and interior of the casing, No. 7 being near the foot of the chimney.

No. of Experiment.	Strokes of Engine a minute.	Position of Shutter.	Indicated H.P. applied.	Indicated H.P. transmitted to the Fan.	Loss in the Engine—expressed in H.P.	Indications of Anemometer 112 A, in Drift at Bank, a minute.	Velocity of Air a minute, calculated from Formula $V = \sqrt{1 \cdot 2337\, R^2 + 18930}$.	Cubic Feet of Air a minute.	Water-Gauge at No. 1 Station, Area 74·27 ft.	Calculated useful effect in H.P.	Calculated per cent. useful effect on the whole Power applied.	Calculated per cent. useful effect on Power transmitted to the Fan.	Water-Gauges. No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
							ft. a min.												
1	20	1	2·59	1·99	·60	265·	324·8	24,123	·200	·76	29·34	38·2	·200	·125	·100	·050	·025	0·00	0·03
2	38	1	9·94	8·37	1·57	450·	518·2	38,487	·600	3·64	36·62	43·5	·600	·550	·250	·125	·100	0·25	0·15
3	38	¾	10·02	8·81	1·21	467·5	537·	39,883	·550	3·45	34·43	39·1	·550	·500	·200	·075	·100	·25	·125
4	39	½	9·72	7·80	1·92	425·	491·5	36,504	·500	2·88	29·63	37·0	·500	·450	·150	·025	·050	·25	·135
5	39	¼	8·21	6·85	1·36	337·5	399·1	29,641	·250	1·17	14·26	17·1	·250	·100	+ ·375	+ ·500	+ ·200	·035	·250
6	41	0	7·63	6·00	1·63	256·25	316·	23,469	·100	·37	4·85	6·2	·100	·000	+ ·400	+ ·475	+ ·150	·025	·065
7	55	1	23·84	20·94	2·90	672·5	759·1	56,378	1·200	10·66	44·71	50·9	1·200	1·100	·400	·275	·300	·05	·200
8	55	..	..	..	..	680·	767·4	56,995	Not recorded.				..	..	..	..	..	..	..
9	57½	1	23·53	19·73	3·80	722·5	813·8	60,441	1·400	13·33	52·40	67·56	1·400	1·350	·500	·325	·350	·05	·310
10	87	1	69·96	58·16	11·80	1030·	1151·8	85,544	2·550	34·37	49·13	59·10	2·550	2·500	1·00	·650	·675	·10	1·200
11	94	1	..	Not indicated.		1266·6	1413·	104,943	3·150	52·09	..	..	3·150	3·200	1·150	·900	·800	·125	1·300

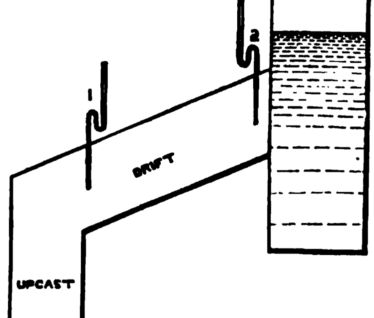
NOTE.—Except where + sign is attached, the water-gauges are all depressions.

Figs. 2808, 2809, indicate the positions of the water-gauges.

2808.



2809.



It is especially worthy of notice that the water-gauge indicated at the inlet is greater than the theoretical result obtained by calculation, every adjustment being correct; so that if h be the height of water-gauge, and h^1 the height computed, as due to the velocity of the extremity of the vanes, then $\frac{h}{h^1}$ is always > 1, and this result is different to that obtained from any other machine ventilator; $\frac{h}{h^1}$ in other cases is > 1 rarely $= \cdot 75$. The cause of this is assignable to the pre-

vention of the return of air-currents into the fan, and the utilization of a part of the power carried off by the discharged air.

In the Elswick experiments the value of h^1 being computed from the formula

$$h^1 = \frac{v^2}{2g} \cdot \frac{12}{815} \text{ inches of water column,}$$

where v = velocity of the extremity of the vanes in feet per second, the following results arise, though the shutter was not varied in each case, as it ought to be, to produce the best results;—

No. of Revolutions a minute	Indicated Water-Gauge (h).	Theoretical Water-Gauge (h^1).	$\frac{h}{h^1}$.
40	·600	·530	1·13
50	·925	·830	1·11
60	1·300	1·191	1·09
70	1·875	1·625	1·15

The relation $\frac{h}{h^1}$ is generally 1·25, and it has been proved by M. Guibal as great as 1·60 in the case of a small volume of air, and the shutter nearly at its lowest. The value of $\frac{h}{h^1}$, if calculated from observations taken in various positions of the shutter, no alteration being made in the pressure of steam, nor in the opening of the regulator-valve, and multiplied by the number of revolutions in each case, say R $\frac{h}{h^1}$, is an indication of the best position of the shutter when such product gives the highest result, for it shows that the minimum resistance is offered to the fan at the same time that a maximum water-gauge is obtained.

It is upon this principle that the position of the shutter can be experimentally tried, for the production of the best economical effect.

The consumption of coals at one boiler, arranged to work this fan, was for twenty-four hours taken over a fortnight, 2 tons 16 cwt., the average speed of the fan being forty revolutions a minute, day and night. This is found to yield sufficient air for the present workings, the quantity passing through the mine being nearly 40,000 cub. ft. a minute. The indicated steam-pressure at the boiler is 35 lbs. to the square inch, the water-gauge at bank near the inlet is ·70 in., and underground ·70 in. (at higher speeds there is a greater depression at bank than underground) the seam being very low, the return air-courses are of small area, and the upcast is a 11-ft. diameter shaft, used for ventilation only. No engineman is required, one of the firemen being instructed to attend to the requisite oiling of the bearings. In some cases the pumping engineman might take the engine in charge; the simple arrangement of all the parts offers the least possible risk of any of them getting out of order.

In order to test the capabilities of the ventilator, the experiments above tabulated were made; and it will be seen, from the calculated useful effect, how much superior are the results obtained to those of previous machines.

We add an account of the performance of the ventilating fan at the Hemingfield Pits of the Elsecar Colliery, by J. J. Atkinson.

In connection with the workings or mine ventilated by this fan, at the Hemingfield Pits, there are two downcast shafts, each 468 ft. in depth. One of these is used as a winding shaft, and is elliptical in section, its transverse diameter being 10 ft., and its conjugate diameter 9 ft.; the other downcast shaft is circular in section, and 10 ft. in diameter, but has three lifts of pumps in it; being the engine-pit.

There are also two upcast shafts, employed exclusively for ventilation, they are both circular in section, the one being 9 ft., and the other 7 ft. in diameter. These two shafts are, near the surface, brought into one, which opens into the central part of one side of the fan.

The downcast shafts are situated at a distance of about 530 yds. to the dip (of the strata) from the upcast shafts; the dip being about 1 in 11, or 3¼ in. a yard.

The workings ventilated by the fan extend about 726 yds. in one direction, and 770 yds. in the other, on the level course of the strata, and embrace about 136 acres.

Description of the Fan.—Diameter, outside of the extremities of the vanes, 22 ft. 8 in.; diameter, outside of the rim, 22 ft. The extremities of the vanes project 10 in. beyond the rim of the fan. Diameter of the fan, on the inside of the rim, 16 ft. 10 in.; width of the vanes, 5 ft.; depth of the same, 3 ft.

The vanes are stated to be fixed so as to form an angle of 45° with a line drawn to them from the centre of the fan. This particular angle, it was stated, had been found to give the best results, by special experiments made for the purpose of finding the best angle for the vanes.

There are twenty-six vanes in the fan, and it has seven arms, to which the rim is attached.

The vanes are not curved, but quite straight.

Description of the Engine.—The fan is driven by a steam-engine, having a vertical cylinder, and a connecting-rod attached to a crank at the extremity of the main shaft of the fan, so that the fan makes a revolution for each double stroke of the engine.

The engine cylinder is 22 in. in diameter.

The length of the stroke of the engine is also 22 in.

The engine is worked by means of three boilers (cylindrical, with hemispherical ends, and having wheel flues), each of which is 30 ft. long, over all, and 5 ft. in diameter. All the three boilers were at work when the experiments were made on the 3rd of October; but it was stated that two of these boilers were ordinarily sufficient to supply steam for driving the fan.

The pressure of the steam during the experiments was 43 lbs. the square inch; but 40 lbs. a square inch was stated to be the ordinary working pressure, that is, the pressure on the boilers.

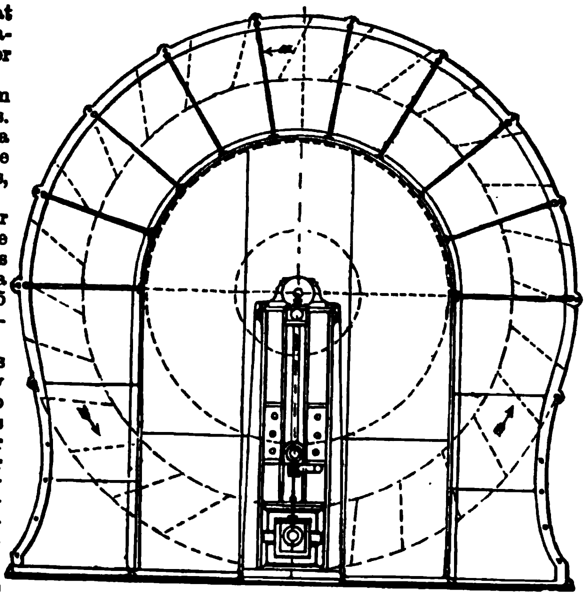
The average quantity of air circulating in the mine, under the ordinary working of the fan, was stated to be 88,000 cub. ft. a minute, with a water-gauge of 0·5 to 0·6 in. at the fan, which includes the shaft resistances.

The average number of strokes of the engine, during the ordinary working of the fan, was stated to be sixty a minute, and the coals consumed $6\frac{1}{4}$ tons in twenty-four hours, or $10\frac{1}{2}$ lbs. a minute. Near to the principal fan an auxiliary fan is erected, to be employed only in the event of the larger fan being stopped for repairs, or from any other cause.

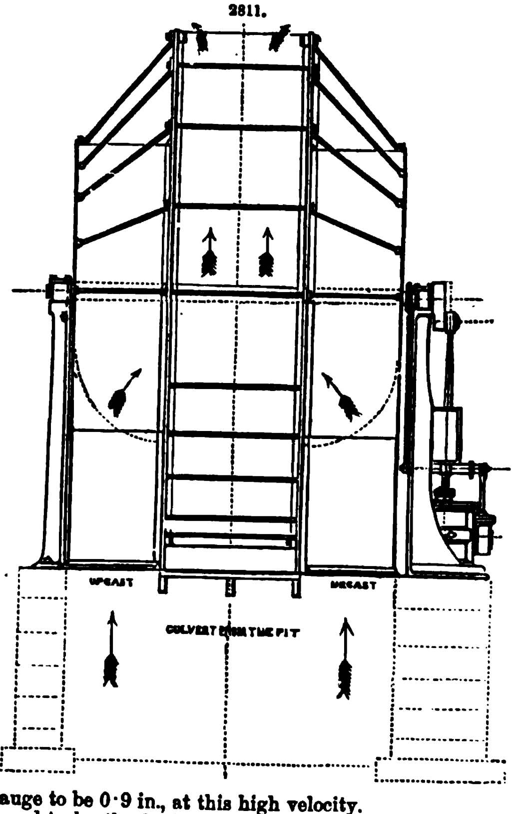
This small fan has an outside diameter of only 14 ft.

Fig. 2810 is a side elevation, and Fig. 2811 a front view of the fan at Simonwood.

2810.



2811.



The air was only admitted on one side of the fan at the Hemingfield Pit; but there is a fan of a similar description at the Simonwood Pit of the Elsecar Colliery, having two air-inlets, one on each side, by means of external iron casings, which render it somewhat more costly.

The following is an account of the experiments and observations made on the 3rd October, 1861;—

	Top.	Bottom.
Temperatures of the downcast shafts	54°	$54\frac{1}{4}$°
Temperatures of the upcast shafts ..	..	$60\frac{1}{2}$°

The air might be considered as being saturated with vapour at the surface, and also in the returns, there being a difference of only half a degree between the wet and dry bulbs of the *hygrometer*.

There are five separate return airways leading into the bottoms of the two upcast shafts, the dimensions of which are given on next page, as taken at the points where the air was measured.

It was intended to have made an experiment with the fan working at seventy revolutions a minute, but owing to some slight defect in the fan, this velocity could only be maintained for a very short time, without endangering its breakage; there was consequently only sufficient time to observe the water-gauge to be 0·9 in., at this high velocity.

About sixty revolutions a minute appeared to be the highest speed at which the fan could be worked with safety.

				Dimensions and Areas of the Five Return Air-ways, at the parts where the Currents of Air were measured.					
				No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	
				ft. in. ft. in.	ft. in. ft. in.	ft. in. ft. in.	ft. in. ft. in.	ft. in. ft. in.	
	Dimensions of the returns			8 5 by 5 8	8 2 by 5 10	6 5 by 5 6	8 9 by 5 11	9 5 by 6 1	
				sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	
	Areas of the returns			47·7	47·64	35·29	51·77	57·28	
	Formulæ applying to the anemometers. No. XIV. $V = R + 49·32$. No. XV. $V = 1·03113.\ R + 27·5$. Where V = velocity of air, and R = revolutions of anemometer a minute.			The currents of air in Nos. 1, 2, and 3 returns were measured with No. XIV. anemomcter.			The currents of air in Nos. 4 and 5 air-ways were measured by No. XV. anemometer		
No. of Experiments.		Inches of Water-Gauge.	Revolutions of Fan a minute.						
	Natural ventilation	0·00	0·00	35	0	51	40	0	Revolutions of anemometer a minute.
	Velocities of wind .	..	..	84·32	40*	100·32	68·75	20*	
	Cub. ft. of air a min.	..	..	4,022	1,906*	3,540	3,559	1,146*	Cubic feet a minute, 14,173.
	Fan working	0·8	60	132	350	382	350	300	Revolutions of anemometer a minute.
	Velocities of wind .	..	..	181·32	339·32	431·32	388·4	336·84	
	Cub. ft. of air a min.	..	..	8,649	19,023	15,221	20,107	19,294	82,294 cubic feet of air a minute.
	Fan working	0·7	60	85	320	310	330	295	
	Velocities of wind .	..	..	134·32	369·32	359·32	367·77	331·68	
	Cub. ft. of air a min.	..	..	6,407	17,594	12,680	19,039	18,998	74,718 cubic feet of air a minute.

No. 2 experiment was made immediately the pit stopped working; and No. 3, not until a few hours after it had stopped. The quantities marked * are only estimated, as the *anemometers* did not move with the currents.

After this, with the view of ascertaining the amount of water-gauge which the fan was capable of overcoming, the top of the upcast (above where the two shafts were confined to a single channel) was contracted by means of a pair of folding-doors, and the following experiments were made;—

No. of Expts.	Inch.
4.—In the ordinary working of the fan, at sixty revolutions a minute, with the top of the upcast open, the water-gauge was observed to be	0·6
5.—With the fan making sixty revolutions a minute, and one-half of the top of the upcast closed, by means of one of the folding-doors, the water-gauge was still about	0·6
6.—With the fan making sixty revolutions a minute, and one of the folding-doors closed, and the other at an angle of 45°, or half closed, the water-gauge was	0·7
7.—With the fan making sixty revolutions a minute, while the ventilation of the mine was entirely suspended by closing off the top of the upcast by means of the two folding-doors, the water-gauge was only	0·8
8.—In a previous trial, with the shafts all open, and the fan making seventy revolutions a minute, during a very short time, the water-gauge was observed, as already stated, at	0·9

The ventilating pressure arising from the air in the ascending parts of its route being of less density than that in the descending parts (owing to an increase of temperature, or of the quantity of vapour in the air), is not only generated, but also expended, in the mine, on overcoming the resistances offered by the shafts and air-ways of the mine, and consequently does not operate upon or influence a water-gauge connecting the outer atmosphere with the fan at the top of the upcast shaft—the place where the water-gauge was ascertained—so that this pressure, which gives rise to the natural ventilation, is not shown by the water-gauge, although, in all the experiments, it is a force operating in conjunction with the additional force created by the fan; the actual power given out by the fan is simply that which is due to the pressure created by it, and is indicated by the water-gauge, taken in connection with the actual quantity of air observed to be circulating at the time.

The remaining, or natural, pressure, not shown by the water-gauge, but arising from the temperature and vapour rendering the air of less density in the ascending than in the descending parts of its route, may be regarded as being sensibly constant; and, although not shown by a water-gauge placed at the fan, near the top of the upcast shaft, owing to its being expended before reaching that point, would operate equally in favour or aid of a furnace or of any other ventilating power that might be employed at the same mine, in lieu of the fan, and ought, therefore, to be neglected in calculating the power due to the fan.

Neglecting, therefore, this source of natural ventilation, the real power given out by the fan, and utilized in the production of ventilation, is, by No. 3 experiment—

$$\frac{74718 \times 0·7 \times 5·2}{33000} = 8·24 \text{ horse-power,}$$

where 5·2 is taken as the pressure in lbs. the square foot, due to 1 in. of water-column.

By No. 2 experiment, on the same principles, the fan gives out, as utilized,

$$\frac{82294 \times 0 \cdot 8 \times 5 \cdot 2}{33000} = 10 \cdot 374 \text{ horse-power.}$$

Now, if we presume that, at the time of making the second experiment, just alluded to, the boiler fires were consuming the ordinary working quantity of $6\frac{1}{2}$ tons of coals in twenty-four hours, or $606\frac{2}{3}$ lbs. an hour, we have a consumption of $\frac{2240 \times 6\frac{1}{2}}{24 \times 10 \cdot 374} = 58 \cdot 48$ lbs. a horse-power, actually utilized, in an hour.

In cases where furnaces are employed to produce ventilation, the consumption of coals a horse-power really utilized in the production of ventilation varies to a great extent, under different conditions as to depth and sizes of shafts, and of air-ways, and as to the relative state of dryness or dampness of the walls or brattice of the shafts; being in some instances much greater, and in others materially less, than the amount just stated as being due to the fan, in this instance.

The following account of the consumption of coals a horse-power utilized each hour by different ventilating furnaces, in use in different collieries, is extracted from page 143 of vol. vi. of the Transactions of the Institution of M. E.;—

No.	Names of Collieries.	Depth of Upcast Column in lineal feet.	Coals consumed per Horse-power utilized per hour.
			lbs.
1	Thornley Five Quarter Seam	556	85·4
2	Thornley Hutton Seam	868	162·4
3	Walker	960	30·5
4	Castle Eden	1038	29·1
5	South Hetton	1212	27·2
6	Wearmouth	1800	29·5
	Averages	$1072\frac{1}{3}$	60·7

It may, however, be remarked that a furnace would have operated under very disadvantageous circumstances with an upcast shaft like that of the Hemingfield Pit at Elsecar Colliery, owing to its being no more than 360 ft., or 60 fathoms, in depth.

Under such a condition, in order to have got the same amount of water-gauge, and consequently the same amount of air as was yielded by the fan in No. 3 experiment—the pressure indicated by the water-gauge being superimposed upon the naturally existing ventilating pressure—an average upcast temperature of $152 \cdot 8^\circ$ would have been required, as will appear from the following considerations.

The head of air-column taken at 54° and 30 in. of mercury, due to the natural difference between the temperature of the air in the downcast and that of the air in the upcast shafts, taken at 54° and $60\frac{1}{2}$° respectively, would be $\frac{60 \cdot 5 - 54}{459 + 60 \cdot 5} \times 360 = 4 \cdot 5$ ft.

But since the temperature of $60 \cdot 5^\circ$ was that of the return air as it reached the bottom of the upcasts, and since there would be a little cooling from the expansion of the air as it ascended the upcast shaft, it is probable that the average temperature of the upcast column was slightly less than $60 \cdot 5^\circ$, and in order to allow for this, in lieu of taking $4 \cdot 5$ ft., only $4 \cdot 16$ ft. of air-column will be assumed as the ventilating pressure arising from the natural difference of the temperatures prevailing in the downcast and upcast shafts respectively.

But, taking the weight of a cubic foot of air, saturated with vapour at 54°, and under a pressure of 30 in. of mercury, at $\cdot 07704$ lb., there would be required, to give a pressure equal to that represented by $0 \cdot 8$ in. of water-column, a further column of such air and vapour of

$$\frac{\cdot 8 \times 5 \cdot 193\frac{1}{3}}{\cdot 07704} = 54 \text{ ft. in height.}$$

Making a total height of such air-column (including that due to natural causes) of $54 + 4 \cdot 16 = 58 \cdot 16$ ft., and the average prevailing temperature, required in the upcast shaft, in order to give such a pressure, will be found from the formula $T = \frac{459\,H + d\,t}{d - H}$.

Where T = the average temperature of the upcast column.

H = the height, in feet, of air-column, arising from the difference of shaft temperatures = $58 \cdot 16$ ft.

d = the depth of the upcast shaft = 360 ft.

t = the temperature of the downcast shaft, and of the air-column H, or 54°.

From whence $T = \frac{459 \times 58 \cdot 16 + 360 \times 54}{360 - 58 \cdot 16} = 152 \cdot 8^\circ$, as above stated.

But, taking the temperature of the return air at $60 \cdot 5^\circ$, and the barometer at 30 in. of mercury (the return air being saturated with vapour), we have

30·000 in. of mercury as the barometrical pressure,
and 0·527 „ „ as the tension of the vapour; leaving

29·473 „ „ as the tension of the air.

Now the weight of a cubic foot of air, at 60·5°, and under 29·473 in. of mercury, is

$$\frac{1 \cdot 32529 \times 29 \cdot 473}{459 + 605^\circ} = \cdot 07519 \text{ lb.}$$

The weight of a cubic foot of vapour of water, at the same temperature, and under a tension or pressure of 0·527 in. of mercury, is $\frac{\cdot 07519 \times \cdot 527}{29 \cdot 473} \times \cdot 622 = \cdot 000833$ lb.

And taking the capacity of water, for heat, at unity, that of air and vapour of water, under a constant pressure, are ·238° and ·475° respectively; so that the capacity for heat, of the returns, passing over the furnace each minute, is equivalent to that of

$$\begin{aligned} &\cdot 07519 \times 82294 \times \cdot 238 = 1472 \cdot 67 \text{ lbs. of water.} \\ \text{and } &\cdot 000833 \times 82294 \times \cdot 475 = \underline{32 \cdot 56} \quad ,, \quad ,, \\ &\text{or, together, to } 1505 \cdot 23 \quad ,, \quad ,, \end{aligned}$$

And admitting that so much of each pound of coal, applied to the furnace, as is actually burnt, yields 13,000 calories or units of heat, the coals required to elevate the temperature of 82,294 cub. ft. of such saturated air from 60·5° to 152·8°, or through the difference of (152·8 − 60·5 =) 92·3°, would be $\frac{1505 \cdot 23 \times 92 \cdot 3^\circ}{13000} = 10 \cdot 687$ lbs.

So that, if even there was no loss of temperature by cooling in the furnace drift and upcast shafts, this would be the necessary consumption of coal by a furnace, to do the same work as the fan, if employed to supersede it, in the ventilation of the Hemingfield Pit at Elsecar Colliery.

But if we presume that one-third of the heat given out by the furnace had been lost by cooling, when the air reached that part of the upcast shaft at which the average temperature prevailed, then the consumption of coals by a furnace, to have given a ventilation of 82,294 cub. ft. of air a minute, at a pressure of ·8 in. of water-gauge (in addition to the natural ventilating pressure), would in this particular case have been $1\frac{1}{2} \times 10 \cdot 687 = 16 \cdot 0305$ lbs. a minute, or $\frac{16 \cdot 0305 \times 60 \times 24}{2240} = 10 \cdot 35$ tons in twenty-four hours, in lieu of only 6·5 tons, used in driving the fan, to produce the same amount of ventilation.

This last result gives for a furnace, in so shallow a shaft, a consumption of 92·71 lbs. of coal a horse-power utilized an hour; compared with one of 58·48 lbs. used for driving the fan, and, if even there were no loss of heat by cooling, in the case of the furnace, the consumption of coal would be 61·81 lbs., compared with 58·48 lbs. a horse-power utilized an hour, as used for the production of ventilation by the fan.

No indicator, friction-brake, or other means, were used to ascertain the actual power of the engine employed to drive the fan; but, as has been stated, the pressure of the steam in the boilers was 43 lbs. a square inch, and the diameter of the cylinder and the length of the stroke were each 22 in.; and as the engine made sixty double strokes a minute when 82,294 cub. ft. of air a minute circulated, it follows that if we allow one-fourth of the pressure of the steam to have been used or lost in overcoming the friction of the machinery connected with the engine and the fan, by condensation, &c., we have

$$\frac{22^2 \times \cdot 7854 \times \frac{3}{4} \times 43 \times \frac{22 \times 2}{12}}{33000} = 81 \cdot 728 \text{ horse-power, as the working}$$

power of the engine. But we have already seen that only 10·374 horse-power was actually realized, in the ventilation produced, which is only 12·69 per cent. of the power, so calculated, for the engine, showing a loss of 87·31 per cent. of that power.

This result is what might have been anticipated from a consumption of so much as 58·48 lbs. of coals a horse-power utilized an hour; the consumption of coals, on the power of the engine, as above calculated, being only 7·42 lbs. a horse-power an hour.

It appears from these experiments that the Elsecar fan is capable of circulating large quantities of air at a low water-gauge, such as is due to the existence, in the mine, of numerous roomy and short air-ways; and that it is not well adapted for overcoming heavy drags or resistances, such as occur where the air-ways are few in number, limited in sectional area, or very long; inasmuch as it was found impracticable to obtain so much as an inch of water-pressure, from the use of the fan, even when the mine was entirely shut off, and no air allowed to circulate in it; beyond any small amount of leakage that might prevail at the folding-doors, over the top of the upcast shaft.

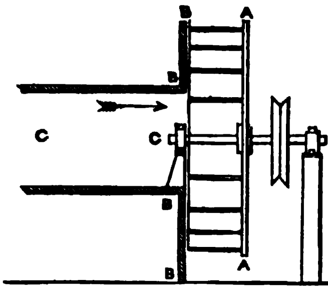
Cochrane observes that this fan appears only to give a utilization of 12·69 per cent. of the power employed, compared with one of about 60 per cent., alleged to be obtainable from machines similar to those known as Struvé's, Fabry's, and possibly one or two other kinds. It has, however, the recommendation of being moderate in first cost, and so simple in construction as to be little liable to get out of repair; and, as the class of coals used are of no very great value, on many collieries, its waste of power in such cases may not stand greatly in the way of its adoption, where the nature of the mine happens to be one of a character to suit its application.

Ventilator.—The name of ventilator is applied, in general terms, to all of those contrivances designed to renew the air in a given space; but in Mechanics the name is more particularly applied to those which operate by centrifugal force. These instruments consist of a certain number of fans, either straight or curved, fixed upon an axis, and revolving between the sides or cheeks of a drum, the circumference of which may be quite open or partially closed. There are two kinds of these ventilators—those which *suck* the air through pipes opening into the cheeks of the drum on a level with the axis, and eject it into the atmosphere with a feeble velocity through all the

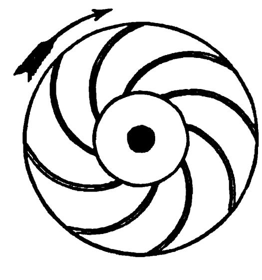
points of the circumference, and those which suck the surrounding air through orifices in the cheeks on a level with the axis, and *blow* it through a pipe communicating with the circumference of the drum. Both of these methods may be combined in one ventilator.

Sucking Ventilators.—Figs. 2812, 2813, represent a sucking ventilator with curved fans. The fans are fixed upon a disc A A, Fig. 2812, perpendicularly with the axis, and revolving with it. The cheek B B has in its centre a circular orifice, to which is fitted a pipe C C, through which the air is sucked. Fig. 2813 shows the arrangement of the curved fans. The rotary motion is com-

2812.



2813.



municated to the axis by means of the pulley p. The way in which the apparatus works will be apprehended without difficulty. As the rotation takes place in the direction of the convexity of the fans, as shown by the arrow in Fig. 2813, there tends to be formed on the concave side a partial vacuum, into which the air of the pipe C C rushes. This air is thrown outwards towards the circumference by the centrifugal force acting upon it, and issues by the canals formed by the fans in a direction nearly opposite to that in which the fans rotate; so that the absolute velocity of egress is very feeble.

The motion of the air in a sucking ventilator gives rise to complex phenomena, and the exact theory of this apparatus has yet to be found. We will, however, give an approximative theory, in order summarily to appreciate its effects. Let P_0 be the pressure in the pipe C C, P the pressure at the point where the air enters between the fans, and v the velocity which the air assumes in virtue of this difference of pressure. Calling the temperature of the air t, and its coefficient of expansion a, we have, according to Bernoulli's theorem,

$$v^2 = 2\,g \times 18304\,(1 + a\,t)\,\log.\frac{P_0}{P}\,. \qquad [1]$$

This velocity is in the direction of the radius, or perpendicularly to the sides of the pipe C C. Let u_0 be the velocity of the fans at the inner circumference; this velocity is perpendicular to v. If, therefore, we denote the relative velocity of the ingress of the air into the canals formed by the fans, by w_0, this third velocity will be the hypothenuse of a rectangular triangle having as its sides u_0 and v. We have, therefore,

$$w_0^2 = v^2 + u_0^2. \qquad [2]$$

Let w be the relative velocity of the air at the opposite end of these same canals, that is, at the outer circumference of the fans; let u be the velocity of the fans at this point. The pressure at the outer circumference being the pressure of the atmosphere P_a, we have, by applying the principle of the effect of the work for the relative motion,

$$w^2 = w_0^2 + u^2 - u_0^2 + 18304\,(1 + a\,t)\,\log.\frac{P}{P_a}\,2\,g. \qquad [3]$$

Let a be the angle of the velocities u_0 and w_0; we thus have

$$\tan.\,a = \frac{v}{u_0}\,. \qquad [4]$$

Let β be the angle which the last element of the fans makes with the outer circumference, and v' the absolute velocity of the egress of the air; this velocity v' will be the resultant of the relative velocity w and the velocity u taken in the contrary direction. We thus have

$$v'^2 = u^2 + w^2 - 2\,u\,w\,\cos.\,\beta. \qquad [5]$$

Let W be the weight of the air which flows off in a second; S the distance between two consecutive fans measured on the outer circumference, and e the thickness of the ventilator, or distance between the disc A A and the cheeks B B. The section of one of the canals will be e S sin. β; and if we suppose all the currents of air moving with the same velocity w, the volume which passes off in a second through one of these canals will be e S sin. $\beta \times w$. This air being at the atmospheric pressure, if Π_a denote the weight of the cubic mètre of air at this pressure and at the temperature t, the weight of air flowing off through one of these canals in a second will be $\Pi_a\,e$ S sin. $\beta \times w$. And consequently, if there are n canals, we shall have

$$W = n\,\Pi_a\,e\,S\,\sin.\,\beta\,w,$$

or, remarking that n S expresses the outer circumference of the fans, the value of which is $2\,\pi\,r$, if r denote the radius of this circumference,

$$W = 2\,\pi\,r\,\Pi_a\,e\,w\,\sin.\,\beta. \qquad [6]$$

Calling the weight of the cubic mètre of air at the pressure P and at the temperature t, Π, and the radius of the inner circumference of the fans or the radius of the pipe O C, r_o, we find

$$W = 2 \pi r_0 \Pi e w_0 \sin. a. \qquad [7]$$

The quantities Π_a and Π may be expressed as functions of the pressures and temperatures corresponding, by the formulæ

$$\Pi_a = 1^k \cdot 3 \frac{P_a}{10334 (1 + a t)}. \qquad [8]$$

$$\Pi = 1^k \cdot 3 \frac{P}{10334 (1 + a t)} \qquad [9]$$

Adding member by member the relations [1], [2], and [3], we obtain, after reductions,

$$w^2 = u^2 + 2 g \times 18304 (1 + a t) \log. \frac{P_0}{P_a} \qquad [10]$$

which will give the velocity w. Usually the pressures P_0 and P_a differ but little from each other: their relation is very near unity, so that w will differ but little from u, that is, *the relative velocity of egress of the air is sensibly equal to the velocity of the outer extremity of the fans*, a result which is confirmed by experience.

The velocity w being given, equation [6] will give P. If we add equations [1] and [2], we have

$$w_0^2 = u_0^2 + 2 g \times 18304 (1 + a t) \log. \frac{P_0}{P}. \qquad [11]$$

Again, equation [7], by substituting the value of Π [9], becomes

$$W = 2 \pi r_0 e w_0 \sin. a \times 1 \cdot 3 \frac{P}{10334 (1 + a t)} \qquad [12]$$

The relations [11] and [12] will give the values of the two unknowns w_0 and P. Equation [1] will then give the velocity v; and equation [5] will give the velocity v'. Equation [4] will give a, the angle which the first element or portion of the fan makes with the inner circumference to allow the air to enter the canals without a shock.

The expression of the effective work is $T_u = W \frac{w_0^2}{2g}$.

The motive work T_m is made up of T_u, plus the work corresponding to the absolute velocity of the air at its egress, that is, $W \frac{v'^2}{2g}$, plus again the work T_f, due to the friction of the air against the sides of the canals, and to unavoidable losses. We have, therefore,

$$T_m = W \left(\frac{w_0^2 + v'^2}{2g} \right) + T_f,$$

and, consequently, the expression of the ratio of the effective to the whole work is

$$\frac{T_u}{T_m} = \frac{w_0^2}{w_0^2 + v'^2 + \frac{2g}{W} \times T_f} \qquad [13]$$

It will be seen that the velocity v' should be as small as possible. To obtain this result, as w differs but little from u, it is evident that we must make the angle β as small as possible; that is, the last element or portion of the fan should be as nearly as possible a tangent to the outer circumference.

Losses due to leakage cannot be computed; the friction may be calculated as for a pipe, when the dimensions of the ventilator are known. To this end, as the relative velocity is variable, we may take the mean of the velocities w_0 and w, and substitute it for U in the formula $\phi = \Pi_1 l \chi \beta U^2$, whence $T \phi = \Pi_1 l \chi \beta U^3$, l denoting the developed length of one of the canals, χ the contour of its mean section, β the coefficient 0·000355, and Π_1 a mean between the values Π_a and Π, which enter into the foregoing calculations.

This approximative theory supposes that the currents of air have the same velocity in a given section of the canal; the velocities are, in fact, different. It supposes, too, that the pressure is the same in a given section; this hypothesis is not realized. Behind the fan a partial vacuum is formed, into which the external air rushes, so that there are two currents of air in a given canal at once, one of which is issuing in virtue of centrifugal force, the other of which is entering in virtue of the difference of pressure of which we have spoken above. These complicated phenomena would require a careful experimental study, one that would be both delicate and difficult, and which has never yet been made.

In general, the effective work, or, in other words, the ratio of the useful work effected by the instrument, to the total work expended on it, is very small; it hardly reaches 0·30 in those which have been constructed with the greatest care; and it often descends as low as 0·18 and even 0·10, especially when the curved fans are avoided, as frequently happens, in favour of straight fans fixed in the direction of the radii. This small amount of useful work effected by the most carefully constructed ventilators is accounted for by the influence of friction, which assumes a high import-

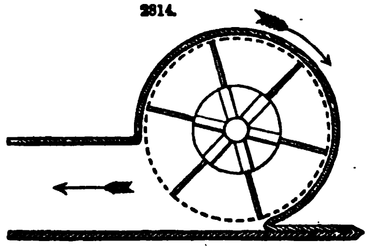
ance from the fact that the air in the canals possesses great velocity. Another cause is the unequal distribution of the velocity, and the pressure in a given transverse section, and the entrance of air through the outer circumference, spoken of above.

The arrangement of the fans has been varied in many ways, and various shapes have been given to the cheeks or sides of the ventilators; but none of these modifications have produced a better result.

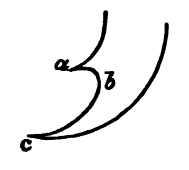
Usually a length of from 1 to 2 mètres is given to the outer diameter; r_0 is made equal to the half of r; the fans are multiplied in proportion as the diameter of the apparatus increases; their number varies generally from 6 to 12. The depth of the fans is a fourth or fifth of the outer diameter. The speed varies from one hundred and twenty up to a thousand revolutions a minute. The rate of speed which gives the best results has yet to be discovered.

Blowing Ventilators.—Fig. 2814 represents a blowing ventilator with flat fans fixed in the direction of the radius. The direction in which the fans revolve is indicated by the arrow These fans are enclosed throughout about three-fourths of their circumference by a drum which prevents the air from escaping; the remaining portion corresponds to a pipe into which the air is driven by the rotation of the fans. We may apply to this kind of ventilator a theory analogous to that which we have explained above for the other kind of ventilator. According to this theory, the fans, instead of being straight, ought to be curved, as shown in Fig. 2815, *a b c*, in order that the air may, on the one hand, enter the canal without shock, and, on the other hand, issue in a direction nearly tangential to the outer circumference. But the small amount of useful work effected by these machines have led constructors to avoid the expensive curved fans; and the straight fans, which have been generally adopted, are fixed in the direction of the radius, or slightly inclined in the direction opposed to that of the rotation.

2814.



2815.



If the central orifice of Fig. 2813, instead of opening into the air, formed the mouth of a pipe communicating with a given space, the ventilator would be at once sucking and blowing. See ADIT. ANEMOMETER. BLOWING MACHINES. BORING. COAL MINING. LAMP, *Safety*. VENTILATION.

FAULTS. FR., *Fente, Fissure*; GER., *Kluft, Gangspatte*; ITAL., *Spostamento*; SPAN., *Dislocacion*.

Faults are a displacement of strata or veins at a fissure, so that they are not continuous.

See BORING AND BLASTING. FAN.

FEED-PIPE. FR., *Tuyau d'alimentation, Tuyau de refoulement*; GER., *Speiserohr*; ITAL., *Tubo d'alimentazione*; SPAN., *Tubo de alimentacion*.

Feed-pipe Connection for Locomotive Engines, invented by Alexander Allan.—Various constructions of feed-pipe connection between locomotive engines and tenders have been used; but the double ball-and-socket plunger pipes, made of brass, are generally applied, in order to have a continuous metallic connection, allowing of blowing steam through into the tender without injury. These, however, are very expensive, requiring great nicety of fitting and much care in their management, and, in consequence of sand and dirt getting in among the movable parts, they involve a serious outlay for maintenance. In practice it is almost impossible to keep them perfectly tight, while if the joints be too tightly screwed up there is risk of the feed-pipes breaking.

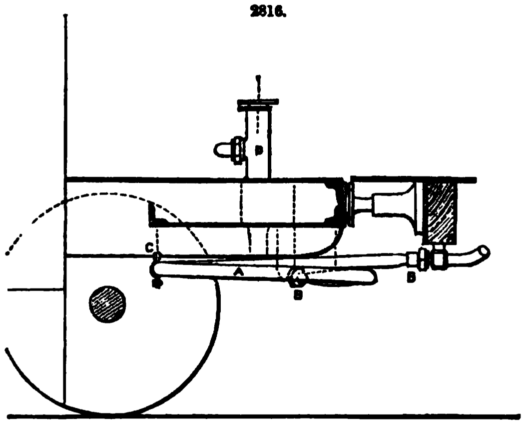
To obviate these defects, and to obtain a continuous metallic connection comparatively inexpensive, and at the same time to present a mechanical combination that should be simple, durable, and efficient, Allan has substituted the connection shown in Figs. 2816, 2817, consisting of a simple brass or copper tube A, coiled in a circle of considerable diameter, so as to have sufficient elasticity to allow for the vertical disturbance due to the unequal deflection of the engine and tender springs, and also for the extreme lateral range required in going round sharp curves, with a minimum strain on the joints. A solid-drawn brass tube is employed, varying from No. 17 to No. 14 wire-gauge in thickness, or ·060 in. to ·085 in., coiled to a circle of 3 ft. to 3½ ft. diameter: see Fig. 2817.

In order to offer less resistance to bending, the tubes are made elliptical in section, about 2½ in. deep by 1½ in. broad: see Fig. 2819. Tubes of circular section 2 in. in diameter, as shown in Fig. 2820, have also been used, but they are more rigid than the elliptical tubes. Experiments were made to ascertain the amount of force necessary to stretch and compress the coiled tube, and also to deflect it vertically and laterally through the extreme range required in practice; and the results show that the elliptical tube has the advantage in elasticity, the first inch of deflection requiring only about 30 lbs. pressure, while a total pressure of from 90 to 100 lbs. is sufficient to produce the extreme deflection of about 3 inches in any direction; up to this pressure there is no permanent set, and consequently no fear of the tube collapsing in any part. The experiments were afterwards extended with the elliptical tube up to 3½ in. movement in any direction, giving a total range of 7 in., up to which the tube may be strained safely; beyond this limit a permanent set is produced. In practice, however, the total range in any direction never exceeds 5 in., or 2½ in. on each side of the central position, leaving a sufficient margin of elasticity to prevent injury to the tube With a thinner tube, or one coiled to a larger circle, an increased range could be obtained if desired.

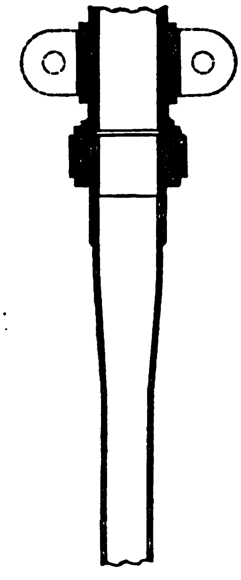
The connecting tube A is attached to both engine and tender by means of the ordinary screw

and tail-pipe couplings B B, Figs. 2816, 2817, the tail-pipes being brazed upon the circular ends of the tube, as shown in the section, Fig. 2818. It is placed above the axle, and suspended to the foot-plate by short chains C, as shown in Fig. 2816, so that the wheels can be removed without interfering with the feed-pipe connection, and it is less liable to damage should the engine get off the rails than the ordinary ball-and-socket couplings. The connecting tube is placed central in the engine whenever practicable, so that the angular deflection produced in running round curves is reduced to the minimum; but it can be fixed without any practical objection in the usual side position of the feed-pipe, as shown in the plan, Fig. 2817, so as to admit of ready application to existing engines and tenders. Figs. 2816, 2817, show the connection applied to an engine fitted with an injector D for supplying the boiler; and the dotted lines E show the end of the tube when a pump is used.

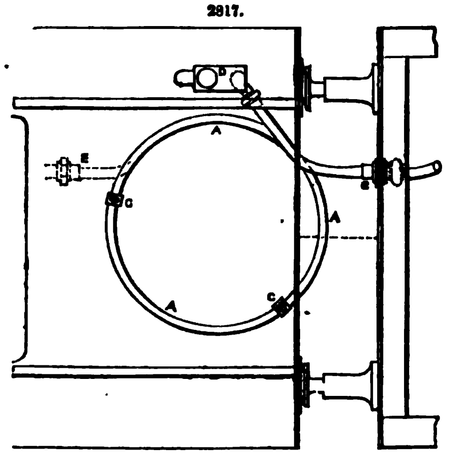
2816.



2818.

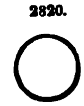


2817.



2819.

2820.



This connection has been fitted to a number of locomotives on the Scottish Central Railway, including some large goods engines; and it has been subjected to severe tests during the last twelve months, and has given satisfaction. In the engines on this railway the plan of coupling between the engine and tender, drawing as well as buffing on a heavy laminated spring, allows more movement than is usual, amounting to a play of 2 in. between the engine and tender, and the connecting tube is 6 in. out of the centre; but, even under these conditions, no failure of the connecting tube has occurred. The dimensions of the engine to which it has been longest attached are;—diameter of cylinder, 16 in.; stroke, 20 in.; driving wheel, 6 ft. diameter; steam-pressure in boiler, 130 lbs. a square inch; the boiler was supplied by a No. 9 injector.

FEED-PUMP. Fr., *Pompe d'alimentation;* Ger., *Speisepumpe;* Ital., *Tromba d'alimentazione;* Span., *Bomba de alimentacion.*

See Details of Engines.

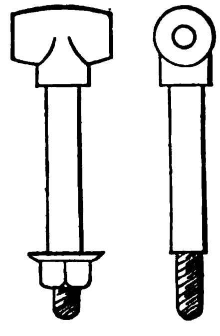
FILBOW, or FILBO. Fr., *Boulon à clavette;* Ger., *Gelochter Nasenbolzen;* Ital., *Chiavarda ad occhio;* Span., *Anillo de amarra.*

Any bow or ball, after the fashion of an eye-bolt, with an attached stem, is termed a filbow when either the stem or bow is in use as a guide, swivel, or double swivel. Fig. 2821 shows the eye-bolt of a gland for a stuffing-box, where the stem is made to serve as a guide. In machinery where the *bow* or *ball* is a guide or swivel, Fig. 2822. Fig. 2823 is a shape given to a filbow when this class of eye-bolt is not intended wholly as a permanent fixture.

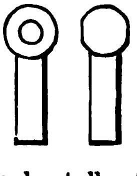
John Fielden, of Rochdale, the inventor of Fielden's Cast Link Chain, p. 336, properly remarks on this technical term, which is as old as the spinning mule or carding engine, "that although not a

2821.

2823.



2822.



local term, but in use in almost all parts of Great Britain amongst educated engineers and machinists, yet this word, like many others of the same class, has never found its way into any Dictionary."

FILE. FR., *Lime*; GER., *Feile*; ITAL., *Lima*; SPAN., *Líma*.

A *file* is a steel instrument having the surface covered with sharp-edged furrows or teeth, used for abrading or smoothing such substances as metals, wood, and so on. A file differs from a *rasp* in having the furrows made by straight cuts of a chisel either single or crossed, while the rasp has coarse single teeth raised by the pyramidal end of a triangular punch. See HAND-TOOLS.

FILE-CUTTING MACHINE. FR., *Machine à taille des limes*; GER., *Feilenhaumaschine*; ITAL., *Macchina da tagliar lima*; SPAN., *Máquina de picar limas*.

It is a remarkable circumstance, says Thomas Greenwood, in the Proceedings of I. of Mech. E., that whilst almost every manual operation in our various manufactures has been either superseded or very materially assisted by the introduction of machinery, the operation of cutting files is still done by hand, and has hitherto been generally considered to be one not admitting of the application of machinery. Several very ingenious machines for the purpose have already been tried, both in this country and in America, but hitherto without any marked success. Large sums have also been expended by some of the leading makers of Sheffield in attempting to introduce file-cutting machines; but the difficulty of the operation, real or imaginary, has been one cause of failure, and another cause has been the very determined opposition on the part of the operatives to the introduction of machinery into any part of the various operations of file-making: indeed, so jealously do the file-cutters guard the art and mystery of their craft, that they do not teach their apprentices how to grind their cutting chisel until they have attained the last year of their legal apprenticeship. The manufacture of files has been kept stationary, instead of advancing and improving like other manufactures, from the mistaken belief on the part of the men that by resisting the introduction of machinery they are preserving their employment. Speaking in 1859, Greenwood observed;—As a further illustration of this mistake it may be mentioned that the tariff of prices for forging files now followed is founded upon the supposition that no improvement has been made in rolling steel in modern times, and that the bars are supplied in the same rude form which was prevalent fifty years ago, thus ignoring the beautiful improvement which has been made in rolling steel; so that the forgers charge the same price for simply drawing down the tang upon a square or round bar of steel for a parallel or equalling file that they do for the entire forging of a half-round taper file-blank of the same length.

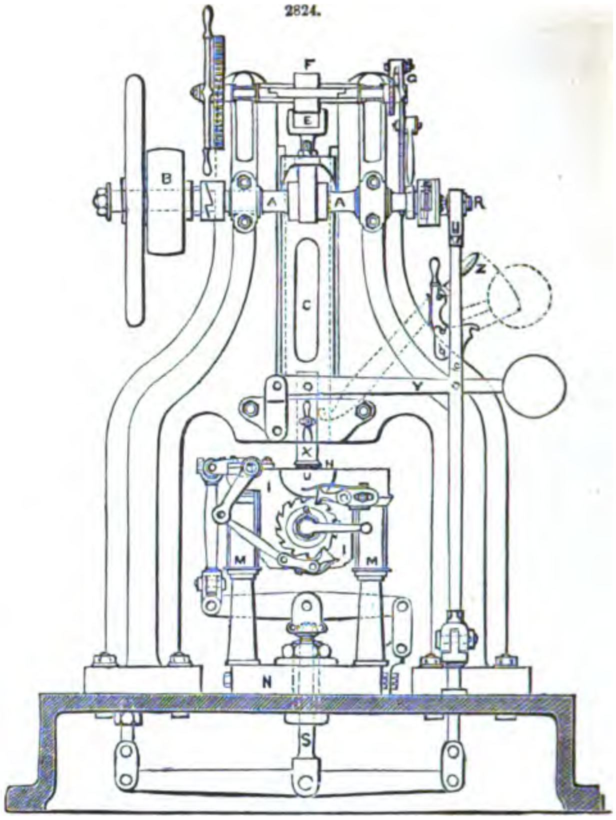
Operations much more difficult than cutting files have been performed by machinery in various manufactures; amongst which may be named, as having taken its rise in the Leeds district, the combing of wool, in which, by the manipulation of the machine itself, the long fibres are selected and delivered into one compartment, and the short fibres into another; an operation which at first sight would appear to require an intelligent and discriminating power. Thomas Greenwood truly observes that the actual process of file-cutting is, however, one of the simplest description. It consists in driving a chisel of suitable form and inclination to a small depth into the prepared surface of the blank, and steadily withdrawing it again; and cutting a file is merely a repetition of this operation. The difficulties to be surmounted are—to present the blank perfectly parallel to the cutting edge of the chisel; to withdraw the chisel from the incision made in the blank without damaging the edge of the newly-raised tooth; to prevent a rebound of the chisel after the blow which drives it into the blank, and before the next blow is struck; to give a uniform traversing motion to the blank, ensuring regularity in the teeth; to proportion the intensity of the blow to the varying width of the file, so as to give a uniform depth of cut; and to perform these operations at such a speed as to make them commercially profitable. In most of the attempts that have been made to accomplish this process by machinery, the idea has been to construct an iron arm and hand to hold the chisel, and an iron hammer to strike the blow; and by this means to imitate as nearly as possible the operation of cutting by hand. The difference in the material used inevitably led to failure; the flexible, and, to some extent, non-elastic nature of the fingers, wrist, and arm, enabled the man to hold the chisel, strike the blow, and then lift the chisel from the tooth, without vibration; not so when the iron hand and hammer are tried to perform the same operation; the vibration consequent upon the material employed frequently caused irregularity in the work, and a ragged and uneven edge on the tooth. The slow speed at which these machines were worked rendered them unable to compete with hand-labour.

In the machine, Figs. 2824 to 2826, the above objections have been nearly, if not altogether, obviated by an ingenious modification in the mode of action. This machine is th invention of M. Bernot, of Paris, and has been already working successfully for some time both in France and Belgium. The blow is given by the pressure of a flat steel spring pressing upon the top of a vertical slide, at the lower end of which the chisel is firmly fixed; the slide is actuated by a cam making about one thousand revolutions a minute, and the chisel consequently strikes that number of blows a minute, thus obviating the vibration consequent upon the blow with an iron mounted hammer, and moving at such a speed as to render any vibration impossible.

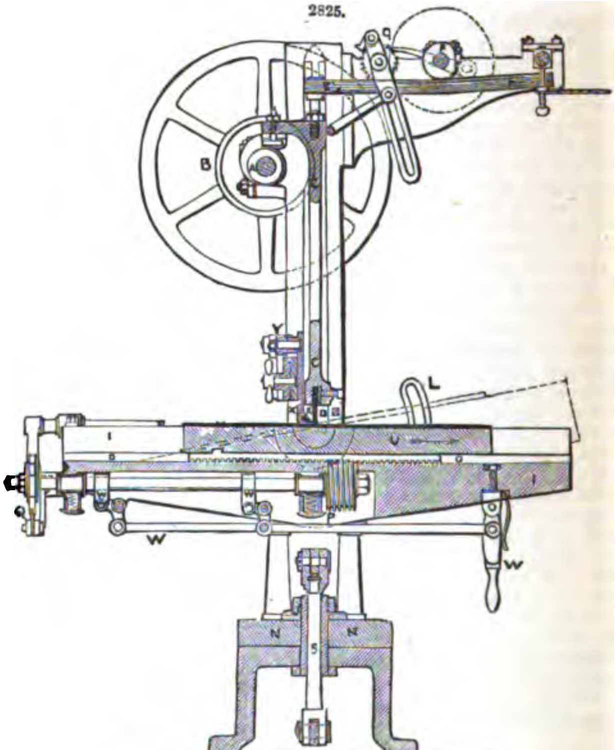
The accompanying Figs. 2824 to 2834, show the various parts of a machine for cutting 18-in. bastard files, which is nearly the largest size required; for the smaller files, machines smaller in proportion are employed, down to one-half the size of that shown in the drawings. Fig. 2824 is a front elevation of the machine; Fig. 2825, a vertical section taken at right angles to Fig. 2824; and Fig. 2826, a plan. In the front elevation, Fig. 2824, some of the parts at the top of the machine which are behind the main framing are shown in front of it for the sake of distinctness, and a portion of the frame at the top is omitted for the same purpose; but the proper position of these parts is fully seen by a comparison with the vertical section and plan, Figs. 2825, 2826.

The main shaft A, Figs. 2824 to 2826, is mounted near the top of the framing, and is driven by a clutch that engages with a similar clutch on the boss of the driving pulley and fly-wheel B, which, when the clutch is out of gear, run loose upon the shaft; the clutch is moved by a hand-lever with suitable notches to hold it in and out of gear, as shown in the plan, Fig. 2826. The vertical slide C is lifted by a cam on the main shaft, and slides between adjustable V guides fixed in the frame of the machine, as shown in the plan, Fig. 2826, and the enlarged plan, Fig. 2834. The cutting chisel D, Fig. 2825, shown black in the drawings, is held in a socket in the bottom of the vertical slide C, and securely fixed by a set screw, as shown enlarged in Figs. 2833, 2834. The blow is given by means of the horizontal flat spring E, Figs. 2825, 2826, which is fixed at the outer end to a

2824.



2825.



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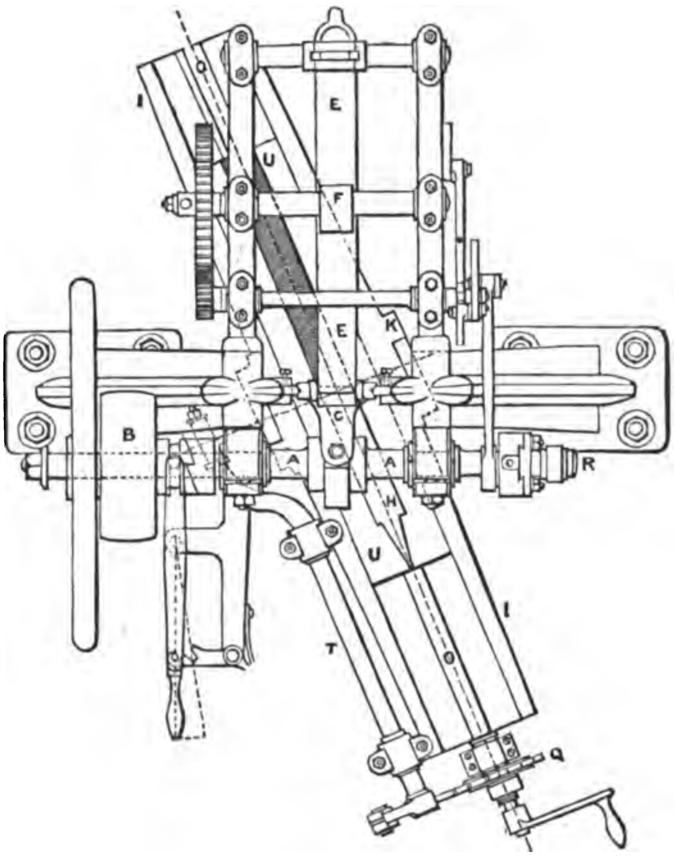

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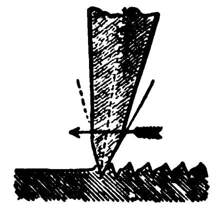

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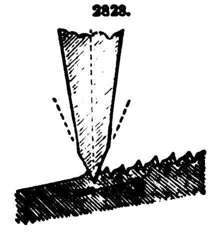

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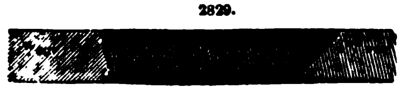

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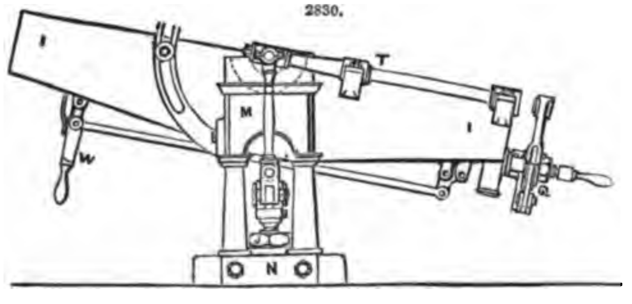

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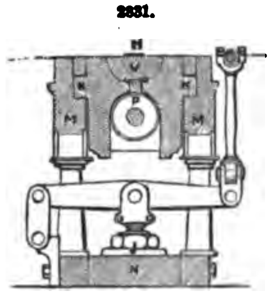

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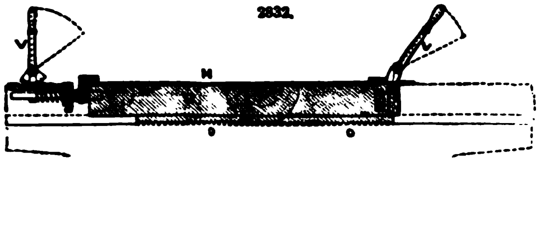
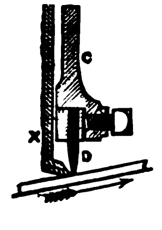
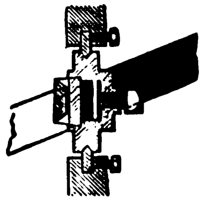


2833.



2834.



rocking shaft carried in a bracket at the back of the main frame; this bracket also carries the pressure cam F pressing upon the middle of the spring and forming the fulcrum against which the spring is bent when the slide C is lifted by the cam on the shaft A, the spring being always in contact with the head of the slide C. The pressure of the spring and consequent depth of cut of the chisel is regulated by an adjusting screw at the outer end of the spring, Fig. 2825; and in the case of cutting a parallel file this pressure is kept the same throughout. But in cutting a taper file the pressure is varied in the same proportion as the breadth of the file varies, so as to maintain an equal depth of cut throughout, by means of the pressure cam F being made to rotate during the traverse of the file; and the radius of the cam is made to increase and diminish in the proportion of the breadth of the file, thus varying the amount of deflection of the spring at each cut in the required proportion. The rotation of the cam is effected by means of the ratchet-wheel G, Fig. 2825, worked by an eccentric upon the main shaft A, Figs. 2824 and 2826, and thrown out of gear when a parallel file is being cut.

The file-blank H to be cut, shown black in Figs. 2824, 2825, is fixed upon a compound bed I, which admits of adjustment to any obliquity horizontally, as shown in the plan, Fig. 2826, by turning upon a strong centre pivot J in the bottom frame; and to any inclination vertically, as shown in Fig. 2830, by rocking upon the centre bearing K, shown in the transverse section, Fig. 2831, which consists of a semicircular trunnion on each side of the file-bed, as shown by the dotted lines in Fig. 2830. The file-bed is adjusted and secured at any required inclination by means of the circular arc L, Fig. 2830, fixed to one of the pedestals M in which the file-bed is carried. These two movements of the bed give the required obliquity of the chisel-cut across the face of the file, and the inclination of the chisel to the plane of the file-face; the chisel itself remaining always vertical. The trunnions K of the file-bed are recessed into the two pedestals M, each supported by two pillars which are connected at the base by a turning plate N, turning on the centre pivot J. The upper end of this pivot is provided with a nut and washer to hold the turning plate N and secure the file-bed I in the required oblique position.

The horizontal movement or traverse of the file between each cut of the chisel is given by means of a rack which slides in a longitudinal groove O in the file-bed I, Figs. 2825, 2826. This rack is advanced the required distance between each stroke of the chisel by the worm P, Fig. 2825, the shaft of which has a ratchet-wheel Q fixed on the outer end, as shown in Fig. 2824, which is worked through a series of connecting-rods and levers from the crank-pin R upon the end of the main shaft A, Figs. 2824 and 2826. In order to provide for the double motion of adjustment of the file-bed I, with an inclination both vertically and horizontally, this feed-motion is communicated through a vertical spindle S, Fig. 2825, passing up freely through the tubular centre pivot J upon which the file-bed turns; the head of the spindle S is connected by a horizontal lever and connecting-rod with swivel-joints to the cranked rocking shaft T, which terminates at the centre line of the trunnions K on which the file-bed rocks, as shown in the plan, Fig. 2826, and side elevation, Fig. 2830; the other end of the rocking shaft T carries a pawl that works the ratchet-wheel Q on the shaft of the worm P, Fig. 2824. The whole of this set of levers is carried by the turning plate N of the file-bed, and turns freely upon the head of the centre spindle S without interfering with their action in driving the worm P.

The upper side of the file-bed I is cut out in a semicircle, as shown in Figs. 2824 and 2831; and a movable semicircular slide U, Fig. 2825, which is of sufficient length to carry the file, is fitted into this semicircle so as to roll freely in the cavity. To the under-side of this slide the rack O is attached by means of a groove and a cross-piece, as shown in Figs. 2825, 2831, 2832. At each end of the slide U suitable fastenings V, Fig. 2832, are attached for holding down the file, with levers, rack, and springs. A handle W, Fig. 2825, with connecting-rods, bell-crank levers, and springs, is mounted underneath the file-bed I for disengaging the worm P from the rack O and allowing the slide U to be pushed freely endways, so as to bring it back easily after the file is cut. On the front of the main frame of the machine is mounted a leveller X, Figs. 2824, 2825, shown in Figs. 2833, 2834, for the purpose of pressing upon the file H and keeping it truly even with the edge of the chisel D; the upper end of this leveller is jointed to a horizontal weighted lever Y, Fig. 2824, one end of which is centred on the frame of the machine by means of a link-joint, and the other end is weighted by a ball; a rest is provided for holding up the lever when required, as shown dotted in Fig. 2824, so as to keep the leveller X clear of the file. Another lever Z, Fig. 2824, is mounted upon a centre in the frame, for the purpose of raising the vertical slide C, which carries the chisel, and is provided with notches to hold it in position.

Mode of Action.—When the file-bed I has been adjusted to the proper position, and the blank H to be cut fixed upon the semicircular slide U, the chisel-slide C is lowered, so as to bring the edge of the chisel down upon the blank. The force of the main-spring E then brings the surface of the blank perfectly even with the edge of the chisel D, in consequence of the rolling movement allowed by the semicircular slide U; in this position it is allowed to remain whilst the leveller X attached to the weighted lever Y is brought down upon the blank: a slot-hole in the middle of the frame of the leveller X allows it to move so much as to bring its lower edge exactly parallel with the edge of the chisel and true to the surface of the blank, in which position it is then secured by hand by the tightening screw, as shown in Figs 2824, 2825. The blank is now slided along to the starting point, and the machine put in motion. If the blank to be cut is a taper flat file, the pawl G which actuates the pressure cam F pressing upon the main-spring E is put in gear, and the deeper side of the cam is gradually brought down upon the spring, causing it gradually to increase the pressure upon the chisel-slide C, and consequently increase the intensity of the blow until the chisel reaches the widest part of the file. When cutting a parallel or equalling file this apparatus is not required. After the file has traversed the length required to be cut, the driving clutch is thrown out of gear and the machine instantly stops; the chisel-slide C is raised by the lever Z, the worm P disengaged from the rack O by the handle W, and the semicircular slide U drawn back; the file is then released and replaced by another, and the operation repeated. After

the first cut has been completed, as shown in Fig. 2829, the second cut is given in the contrary direction across the file, by turning the file-bed I round to the proper obliquity. Every description of round or half-round files is cut in this machine by the use of a revolving bed and dividing apparatus.

In regard to the durability of the cutting chisels in this machine, it is remarkable that they cut five times as many files as can be cut by hand without re-sharpening; and the reason seems to be that the chisel is driven into the blank and withdrawn again in a perfectly straight line, and without any rubbing action; whereas in hand-cutting, the fine edge of the chisel is rubbed a short distance along the surface of the blank until it comes in contact with the last raised tooth, which is the only guide the hand-cutter has to produce regularity of cut. Fig. 2827 is a diagram of the file-teeth and chisel, exhibiting the action of the chisel in raising the teeth in hand-cutting, and its inclined position; and Fig. 2828 is a corresponding diagram of the chisel in this machine, showing the vertical position of the chisel and the inclination of the file travelling underneath it.

In the files cut by this machine the teeth are raised with perfect regularity, and consequently when the file is used each tooth performs its proper share of work; whereas in hand-cutting, from the varying power of the muscles, especially towards the close of the day, it is impossible to produce such perfectly uniform work.

FILTER. Fr., *Filtre;* Ger., *Filter, Seiher;* Ital., *Filtro;* Span., *Filtro.*

See Water-works.

FIRE-ARMS. Fr., *Armes à feu;* Ger., *Feuerwaffen;* Ital., *Armi da fuoco;* Span., *Armas de fuego.*

Trials of small fire-arms and accoutrements have recently been made by a Board of American officers at St. Louis. The particulars, data, and results of these trials, which we give, are taken from the New York Army and Navy Journal.

The Board met at St. Louis Arsenal, March 2, 1870, in pursuance of orders. Captain K. R. Breese, U. S. navy, was present during all the experiments of the Board until April 5, 1870. General J. H. Potter was deputed to conduct the experiments and tests determined on by the Board. These experiments were commenced March 11, and continued till their completion, May 23, 1870.

The following is a list of the arms, accoutrements, and equipments received at the St. Louis Arsenal, under the provisions of General Orders No. 72, and examined by the Board, namely;—

Rifles.

1 Remington rifle, cal. 50, No. 286, from Springfield armoury.
1 Springfield breech-loading rifle musket, cal. 50, mod. 1868, from Springfield armoury.
2 Peabody (Wessely) rifles, cal. 42 (withdrawn).
1 Peabody (Wessely) rifle, cal. 42.
1 „ (self-cocking) rifle, cal. 42.
2 „ (Spanish) rifles, cal. 43.
2 „ (Roumanian) rifles, cal. 45.
2 „ (Springfield) „ cal. 50.
1 Remington rifle, cal. 42, No. 2.
1 Remington rifle, cal. 44, No. 3, sword bayonet.
1 Remington rifle, cal. 50, No. 4.
1 Remington rifle, cal. 51, No. 5, triangular bayonet.
1 Remington (Spanish) rifle, cal. 43.
1 „ (Ryder) „ cal. 50.
1 „ (modified) „ cal. 50.
2 Roberts' (Springfield) rifles, cal. 50, U. S. bayonets.
1 Roberts' (Springfield) rifle, cal. 50, No. 4, U. S. bayonet.
1 Roberts' (Jackson's improvement), cal. 50.
1 „ (Starr's „), cal. 50.
1 „ centre-lock rifle, cal. 50.
1 Berdan's rifle, cal. 42.
1 Colt's rifle, cal. 42, triangular bayonets.
1 „ cal. 50, „
1 Thieme (Baxter's), cal. 50, U. S. bayonet.
2 Triplett and Scott rifles, cal. —.
1 Sharp's musket, cal. 50, U. S. bayonet.
1 Ward-Burton rifle, cal. 42, triangular bayonet.
1 Ward-Burton rifle, cal. 45, sword bayonet.
1 „ cal. 50.
1 Hubbell rifle, cal. 50.
1 Martini-Henry rifle (long block), cal. 45.
1 „ (short block), cal. 45.
1 Morgenstern rifle, cal. 42.
1 „ barrel, cal. 50.
1 Conroy rifle, cal. 42.

Carbines.

1 Remington carbine, cal. 44, No. 1.
1 Roberts' centre-lock carbine, cal. 50.
1 Sharp's carbine, cal. 50.
1 Remington carbine, cal. 50, from Springfield armoury.
1 Sharp's carbine, cal. 50, from Springfield armoury.
1 Spencer carbine, cal. 50 (Stabler attachment), Springfield armoury.
1 Springfield carbine, cal. 50 (Stabler attachment), Springfield armoury.
1 Conroy carbine, cal. 45.

Pistols.

1 Remington revolver, cal. 44, Springfield armoury.
1 National Arms Company revolver, cal. —.
1 Remington single pistol (modified), cal. 50.
1 „ single-barrelled pistol, cal. 50.
4 Remington revolvers, cal. 44, Nos. 2, 3, 4, and 5 respectively.
1 Smith and Wesson revolver, cal. 44.
1 Whitney Arms Company revolver, stationary breech, cal. 44.
1 Whitney Arms Company revolver, revolving breech, cal. 44.

Bayonets.

2 Remington rifles, cal. 50, with Colonel Anson Mill's bayonet attachment.
1 contract rifle musket, mod. 1861, cal. 58, with P. A. Oliver's bayonet attachment.
1 contract rifle musket, mod. 1863, cal. 58, with trowel bayonet in stock; Captain De Witt C. Poole.
25 trowel bayonets and scabbards; Lieut. E. Rice, U. S. army.

Miscellaneous.

Dr. Hay's attachment to Springfield breech-loader rifle musket, cal. 50, mod. 1868.
Dr. Hay's attachment to Remington revolver, cal. 44.

MISCELLANEOUS—*continued.*

Dr. Calver's automatic extractor for Colt's revolver.

Contract rifle musket, cal. 58, mod. 1869, with hair trigger.

Springfield breech-loader rifle musket, cal. 50, mod. 1866, with firing-pin of proper length to explode but not pierce the primer.

4 sets of tools for reloading Berdan cartridges, cal. 42, 45, and 58 respectively.

2 sets of tools for reloading Berdan cartridges, cal. 50.

Cartridges from J. W. H. Gieseler, New York.

ACCOUTREMENTS AND EQUIPMENTS.

Baxter's accoutrements; Sherlock's accoutrements; Snider's accoutrements; Seymour's accoutrements; Penrose's accoutrements; Horstman's accoutrements; cooking canteen; metallic tompion; picket-pin; A. W. Lee's knapsack; O. E. Wood's knapsacks (2); Lieutenant W. C. Manning's knapsack; Colonel G. K. Mizner's knapsack and saddle-bags; Captain J. Clifford's knapsack and cartridge-belts; General Hoffman's bayonet-scabbard attachment; William Cline's baggage-supporter; Charles Ewing's tent overcoat; two tents (General B. S. Roberts); bridle and bit.

2 cartridge boxes, different sizes (D. W. C. Baxter).

1 cartridge box (C. H. F. Thieme).

6 cartridge boxes, different sizes (Captain S. A. Day).

1 cartridge box and belt (Captain W. F. Brewerton).

1 cartridge box (Lieutenant C. L. Best).

2 cartridge boxes (Lieutenant J. R. McGinness).

1 cartridge-box magazine (J. M. Hawkins).
1 „ (Kilborn Knox).
1 „ (A. D. Laidley).

1 cartridge box (Lieutenant Thomas Connolly).

4 cartridge boxes, cavalry, with belts and pouches (Lieutenant J. G. Butler).

4 cartridge boxes, infantry, with belts and pouches (Lieutenant J. G. Butler).

1 cartridge belt with detachable thimbles and tompions and belt-plates.

10 cartridge belts and plates (Colonel Anson Mills).

1 cartridge box (Captain N. H. Coster).
4 „ boxes (C. Howlett).
1 „ box (General B. J. Roberts).
1 „ „ (General A. Baird).
1 „ „ (Captain Clifford).
1 „ „ (General Morris).
2 „ boxes (Benjamin Loyd).
1 „ box holster, leather (Lieutenant Thomas Connolly).

1 cartridge-box holster, wood (Lieutenant Thomas Connolly).

1 cartridge box (Lieutenant Thomas Connolly).

It was decided to confine the experiments with fire-arms to tests of the qualities of the breech mechanism of the various systems submitted to the Board, using the ammunition furnished by the inventors, and subjecting each arm to the same test as far as practicable.

The following programme of experiments was adopted, namely;—

I. *Simplicity of Construction.*—Each arm to be dismounted, examined, and the number of its pieces to be noted.

II. *Accuracy of Fire.*—Test: fifteen shots to be fired from a fixed rest, at a target. Distance 100 yards.

III. *Rapidity of Fire.*—Test: twenty-five shots to be fired from the shoulder; fair aim to be taken at the target. Distance, 100 yards.

IV. *Endurance.*—Test: each gun to be fired at a target 500 times from a fixed rest; distance, 100 yards. The arm to be allowed to cool at the end of each 100 rounds, but not to be cleaned during the test. At the end of this test the arm to be cleaned and examined to ascertain its condition.

V. *Effects of Exposure to the Weather and Firing.*—Test: 400 rounds to be fired without cleaning the arm; 100 on each alternate day. The arm to be exposed to the effects of the sun and rain (or water artificially applied) during each day of the test, and the exposure continued for three days thereafter. The arms to be cleaned and examined.

VI. *Effects of Sand and Dust on the Breech Mechanism.*—Test: eight shots to be fired; then fine dry sand to be sifted over the breech mechanism when closed, and eight shots fired; then fine dry sand to be sifted over the same parts when open, and nine shots fired. The sand to be removed in each case by shaking the piece, or using only the hand. The piece then to be examined and cleaned.

VII. *Effects of Salt Water.*—Test: the arm to be placed for three hours in brine, covering the breech mechanism and chamber; then to be exposed in the open air until the next day, and fifty shots to be fired.

VIII. *Effects of Defective Ammunition.*—Test: the arm to be fired with six cartridges rendered defective in the following manner;—1st. One cut longitudinally from the end of the case to the ribs, and placed in the chamber with the cut upward. 2nd. One cut longitudinally from the end of the case to the rim, and placed in the chamber with the cut downward. 3rd. One to be cut helically from the end to the rim. 4th. One to be cut at the base, so that the firing-pin in firing will pierce it. 5th. One to be pierced through the base at four points. 6th. One to be filed through the rim.

IX. *Strength of the Breech Mechanism.*—Test: the arm to be fired once with a double and once with the triple charge of powder and lead.

The results with the best samples of the six principal systems reported upon by the Board are as follows;—

I.—REMINGTON RIFLES. Fig. 2835.

1.—*Remington Rifle modified so as to load at the half-cock, cal.* 50, *sent by Colonel Schofield.*

I. Was dismounted, examined, and found to consist of fifty-five pieces.

II. This arm was fired with the United States' cartridges for accuracy.

III. The arm was fired for rapidity. Time, 2 min. 23 sec. One cartridge failed to ignite. Barrel slightly leaded.

IV. Arm tested for endurance.

First 100 rounds; time, 11 min. One cartridge failed to ignite. Barrel slightly fouled. Distance between extreme shots, 30 in.; cases extracted with difficulty.

Second 100 rounds; time, 10 min. 30 sec. One cartridge failed to ignite. Distance between extreme shots, 34 in.

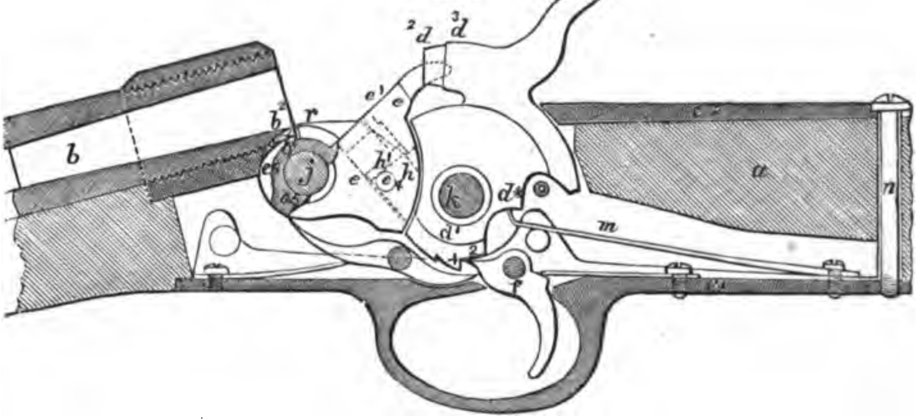
Third 100 rounds; time, 11 min. Six cartridges failed to explode. Distance between extreme shots, 68 in.

Fourth 100 rounds; time, 12 min. Six cartridges failed to ignite. Balls ranged wild.

Fifth 100 rounds; time, 11 min. Five cartridges failed to explode. Shots all over target.

The arm worked well all through the test; many of the cases were drawn with difficulty. The main-spring worked with much friction on the hammer, and small particles of iron were found in the breech mechanism. Barrel much fouled and leaded.

2835.



Remington's latest Patent Breech-loading Rifle.

V. Arm was exposed and fired as prescribed in the fifth test, from April 7 to April 16, and worked freely throughout this trial. No additional signs of weakness.

VI. The arm was subjected to the sand test, and worked freely throughout this trial. Some sand was found in the inside of the guard-plate among the springs.

VII. Arm subjected to the salt-water test. It was rusty, but worked freely.

VIII. Arm fired with defective cartridges. There was a slight escape of gas from the fifth, and much gas escaped from the sixth cartridge. Piece uninjured.

IX. Test of strength by firing increased charges. After the second charge the breech-block moved very stiffly. The lower portion of the barrel was pressed against the breech-block. The lower portion of the chamber was enlarged.

2.—*Remington Rifle, Springfield barrel, No. 4, cal. 50, sent from Remington and Sons.*

I. Was dismounted, examined, and found to consist of fifty-five pieces.

II. This arm was fired with the Sharp's (Martin) cartridge for accuracy.

III. The arm was fired for rapidity; time, 2 min. 3 sec.

IV. Arm tested for endurance with United States' cartridges.

First 100 rounds; time, 7 min. 5 sec. Four cartridges failed to ignite. Dispersion of balls, 25 in. by 21 in.

Second 100 rounds; time, 5 min. 28 sec. One cartridge failed to ignite. Dispersion of balls, 22 in. by 19 in.

Third 100 rounds; time, 4 min. 57 sec. Dispersion of balls, 20¼ in. by 23 in.

Fourth 100 rounds; time, 5 min. 7 sec. Two cartridges failed to ignite. Dispersion of balls, 24 in. by 20 in.

Fifth 100 rounds; time, 4 min. 40 sec. One cartridge failed to ignite. Dispersion of balls, 24 in. by 20 in.

The arm worked freely throughout this test; the barrel was very little fouled. No leading. No signs of weakness or wear in any of the parts.

V. Arm was exposed and fired as prescribed in the fifth test. It was very rusty, but worked freely throughout, and showed no signs of weakness or wear in any of the parts.

VI. Arm was subjected to the sand test and worked freely; some sand was found in the inside of the guard-plate.

VII. Arm was subjected to the salt-water test, and, though very rusty, worked freely. No signs of weakness.

VIII. Arm fired with defective cartridges. No apparent escape of gas in the first three. The case of the second extracted with difficulty. Gas escaped in the fourth and fifth, and in the sixth cartridge a flame was seen above the breech-block. It worked freely and was not injured.

IX. Arm tested for strength with increased charges. After the second charge the breech was opened with difficulty another shell wa not easily extracted. The chamber was slightly enlarged near the extractor. The piece otherwise uninjured.

The breech-block of this arm differs from the one submitted to the Board from the Springfield armoury in that it is without a groove in its front underneath the barrel, and is somewhat stronger in rear of the pivoted pin. The shell extractor is placed somewhat nearer the bottom of the chamber.

II.—Springfield Breech-loading Rifle Musket.

Springfield Breech-loading Rifle Musket, cal. 50, *No.* 14,515, *sent from Springfield Armoury.*

I. Was dismounted, examined, and found to consist of sixty-two pieces.

II. This arm was fired with the United States' cartridge for accuracy.

III. The arm was fired for rapidity; time, 2 min. 33 sec.

IV. Arm tested for endurance.

First 100 rounds; time, 11 min. 30 sec. Barrel slightly fouled.

Second 100 rounds; time, 11 min. Distance between extreme shots, 22½ in.

Third 100 rounds; time, 11 min. Distance between extreme shots, 17½ in.

Fourth 100 rounds; time, 10 min. 30 sec. Distance between extreme shots, 21½ in.

Fifth 100 rounds; time, 9 min. 30 sec. Distance between extreme shots, 21 in.

One cartridge failed to ignite during this test. Barrel slightly fouled; no leading.

The arm was cleaned and examined; no sign of weakness or wear in any of the parts. The extractor worked well, throwing the cases clear of the piece in every instance.

V. This arm was exposed and fired, as prescribed in the fifth test, from April 7 to April 16, and worked freely throughout this test. It was very rusty, especially in the receiver. No signs of wear or weakness in any of the parts.

VI. The arm was subjected to the sand test. It worked freely throughout this test; but very little sand remained in the receiver.

VII. Arm was subjected to salt-water test, and was quite rusty. It worked freely; no signs of wear or weakness.

VIII. Arm fired with defective cartridges. No apparent escape of gas in the first three. These shells extracted easily. In the fourth some gas passed up the firing-pin, and blackened the face of the hammer. Great escape of gas from the fifth and sixth. No signs of weakness or injury in any of the parts. The gun worked well.

IX. Arm was tested for strength with the increased charges. The effect of the second charge was to blow off the entire base of the case. No injury to the piece. Great escape of gas. Gun worked stiffly. Arm examined. No signs of wear or weakness in any of the parts.

III.—Sharp's Rifle Musket.

Sharp's Rifle Musket, cal. 50, *sent by Sharp's Rifle Manufacturing Company.*

I. Was dismounted, examined, and found to consist of seventy-eight pieces.

II. This arm was fired with the Sharp's (Martin) cartridge for accuracy.

III. The arm was fired for rapidity; time, 2 min. 41 sec. One cartridge failed to ignite. No leading of the barrel.

IV. Arm tested for endurance.

First 100 rounds; time, 11 min. Two cartridges failed to ignite. Dispersion of balls, 11 in. by 13 in. Barrel slightly fouled. No leading.

Second 100 rounds; time, 9 min. Three cartridges failed to ignite. Dispersion of balls, 34 in. by 9 in.

Third 100 rounds; time, 7 min. Dispersion of balls, 16 in. by 9 in.

Fourth 100 rounds; time, 5½ min. Dispersion of balls, 15½ in. by 7 in.

Fifth 100 rounds; time, 6 min. Eight cartridges failed to ignite. Dispersion of balls, 20 in. by 10 in.

The arm worked freely throughout the test. Fouling of barrel not increased after the first 100 rounds. No leading.

V. Arm exposed and fired, as prescribed in fifth test, from April 7 to April 16, and worked freely throughout the test. The front guard-screw was found to be broken. No other signs of wear or weakness in any of the parts. Arm slightly rusted.

VI. The arm was subjected to the sand test. Two cartridges failed to ignite. Arm worked freely, and very little sand remained in the breech mechanism.

VII. Arm subjected to the salt-water test, and though quite rusty worked freely. No signs of wear or weakness.

VIII. Arm fired with defective cartridges. In the fourth cartridge gas passed up the firing-pin. Gas escaped from above and below the breech-block. Piece not injured.

IX. Arm tested for strength with increased charges. The second charge blew off the base of the case, so that the extractor could not remove it from the chamber. Piece not injured, and worked freely.

IV.—Morgenstern Rifle.

Morgenstern Rifle, cal. 42, *sent by Herman Boker and Co.*

I. Was dismounted, examined, and found to consist of forty-four pieces.

II. This arm was fired for accuracy with the Berdan cartridge (greased). Three cartridges failed to ignite.

III. The arm was fired for rapidity; time, 2 min. 46 sec. Ten cartridges failed to ignite. The cartridges were partially freed from the external lubricant on the ball patch, and the arm again

fired for rapidity; time, 2 min. 25 sec. Seven cartridges failed to ignite. Stock slightly split at the recoil shoulder on both sides of the barrel.

IV. Arm tested for endurance.

First 100 rounds; time, 14 min. 30 sec. Dispersion of balls, 30 in. by 12½ in. Many of the cartridges failed to ignite.

Second 100 rounds. The seventy-fifth cartridge failed to ignite, after which twelve cartridges were tried, and all failed to ignite. Arm removed, as it would not ignite the cartridges.

The same breech mechanism having been fitted to the Springfield barrel, cal. 50 (sent with the rifle), was again tested for endurance with the Sharp's (Martin) cartridge, unpatched ball.

First 100 rounds; time, 6 min. 8 sec. Dispersion of balls, 20 in. by 32 in. Twelve cartridges failed to ignite.

Second 100 rounds. The seventy-eighth cartridge failed to ignite, as did several which were immediately afterwards tried. On examination of the breech-block it was found that the hammer shoulder washer was partially unscrewed, so as to prevent the point of the hammer from projecting sufficiently to ignite the cartridges.

The arm having been cleaned, and the shoulder washer screwed into its proper position, it was tested again for endurance.

First 100 rounds; time, 8 min. 22 sec. Thirty-five cartridges failed to ignite. Dispersion of balls, 41 in. by 28 in.

Second 100 rounds; time, 7 min. 15 sec. Thirty cartridges failed to ignite. Dispersion of balls, 25 in. by 16 in.

Third 100 rounds; thirteen cartridges tried; eight failed to ignite. The arm was withdrawn, and a stronger spring (one sent with the arm for the United States, cal. 50 cartridge) was inserted, and the firing resumed. Dispersion of balls, 14 in. by 16 in. Seven cartridges failed to ignite.

Fourth 100 rounds; time, 10 min. 40 sec. Sixteen cartridges failed to ignite. Dispersion of balls, 34 in. by 22 in.

Fifth 100 rounds; time, 6 min. 7 sec. All the cartridges ignited. Dispersion of balls, 55 in. by 40 in. Barrel somewhat fouled slightly, and leaded. The main-spring did not work freely, owing to too much friction.

V. This arm was exposed and fired, as prescribed for the fifth test, from April 19 to April 28. The arm was very rusty in the inside of the receiver, but the working parts were free from rust and in good working order. The upper end of the thumb-piece was broken during the firing, and was replaced by one of a different pattern (sent with the arm).

VI. Arm was subjected to the sand test, and worked freely throughout; and but very little sand remained in the receiver.

VII. Arm subjected to the salt-water test, and though rusty worked freely. No signs of wear or weakness.

VIII. Arm fired with defective cartridges. Gas escaped from the last three cartridges. The last one threw the hammer back to half-cock. Arm uninjured.

IX. Arm was tested for strength with increased charges. The second charge broke the face-plate off its shoulder and cracked it radially in five places. Hammer thrown back to half-cock. The base of the case was blown off. Except the face-plate, the piece was uninjured.

V.—Martini-Henry Rifle, Fig. 2836.

1.—*The Martini-Henry Rifle, cal.* 45 (*short breech-block*), *sent by F. Martini, Switzerland.*

I. Was dismounted, examined, and found to consist of sixty-one pieces.

II. The arm was fired for accuracy, with the Boxer cartridge (bottle-shaped), paper-patched ball. In three instances the hammer pierced the primer.

III. The arm fired for rapidity; time, 6 min. Sixteen cases were forced out with the ramrod. In some instances the base became detached by the ramrod, and the remainder of the case was removed with pliers.

IV. Arm tested for endurance.

First 100 rounds; sixty shots fired. After the fifth cartridge every case was removed with the ramrod, or with pliers. On examination it was found that the cases were covered with a lacquer. This was removed from the remainder of the 100 rounds by means of alcohol. The cases were readily drawn by the extractor, with five exceptions, when the ramrod was applied. Dispersion of balls, 17 in. by 27 in.

There being but 250 cartridges received for each Martini rifle, the number of cartridges used in most of the tests for these arms was necessarily reduced, and one test omitted. One hundred and fifty cartridges were to be used in the fourth test.

Fifty rounds, from some of which the lacquer was removed, were fired. The case of those from which the lacquer was wiped extracted easily; the others it was necessary to force out with the ramrod. In one instance the extractor removed the iron base of the case without starting the shell, and it was removed with pliers. The case of the forty-sixth cartridge could not be removed, even with the rammer and pliers. The test was discontinued. The arm worked stiffly throughout this test. The fifth test was omitted.

VI. Arm subjected to sand test; three shots fired. After the first shot the sand was sifted over the breech mechanism, closed, and one shot fired. Then the sand was sifted over the breech mechanism when open, and one shot fired. The breech mechanism worked freely, but did not extract the cases. Sand was found in the receiver, on the guard-plate, and in rear of the breech-block.

VII. The arm was subjected to the salt-water test, and four shots fired. Arm somewhat rusted, but worked freely. In each instance the cases were extracted by the extractor on second trial.

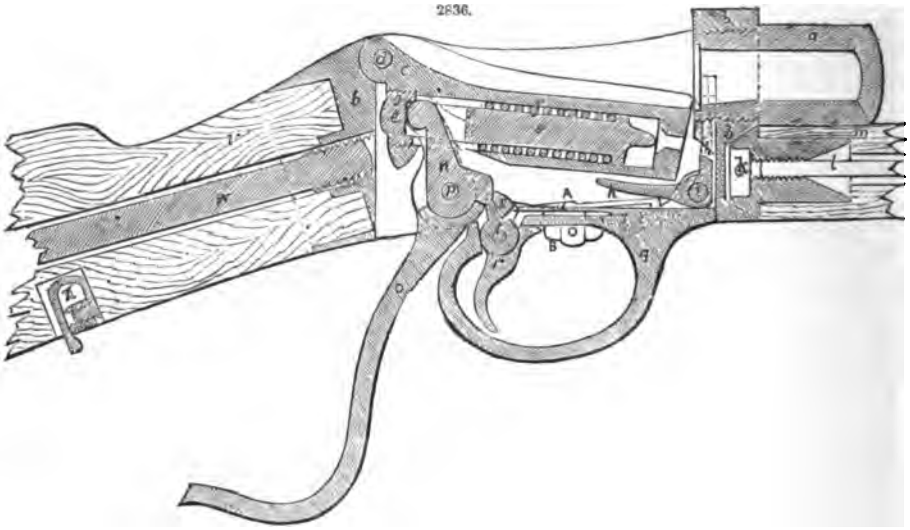
VIII. Arm tested with defective cartridges. No escape of gas from the first three cartridges.

Gas escaped at the breech-block from the fourth and fifth. Great escape of gas from the sixth cartridge. The lever was unlocked, and the breech-block was slightly lowered.

IX. Arm tested for strength by firing increased charges. Gas escaped from the breech and unlocked the lever. Arm uninjured.

No signs of wear or weakness, with the exception that the lever was unlocked in one instance by firing a defective cartridge, and in two instances by firing increased charges.

2836.



The Martini-Henry Rifle.

2.—The Martini Rifle, cal. 45 *(long block), sent by F. Martini, Switzerland.*

I. Was dismounted, examined, and found to consist of sixty-two pieces.

II. The arm was fired for accuracy, with the Boxer cartridge (cylindrical paper-patched ball).

III. Arm fired for rapidity; time, 2 min. 38 sec. The cases were not extracted in every instance the first time the breech-block was opened.

IV. Arm tested for endurance with 150 rounds.

First 100 rounds; time, 12 min. Dispersion of balls, 35 in. by 43 in. Two cases were removed with the ramrod. In one instance the base of the shell was removed by the extractor without starting the case. The base was pulled off by the extractor without starting the case, which was removed with pliers. In some instances the primers were pierced.

Fifty rounds. Dispersion of ball, 43 in. by 21 in. The cases, with three exceptions, were drawn by the extractor. Arm worked stiffly; barrel slightly fouled; no leading.

V. Weather test omitted.

VI. Arm subjected to the sand test; three shots fired. After the first shot, sand was sifted over the breech mechanism, closed, and one shot fired; then sand was sifted over the breech mechanism open, and one shot fired. After the second application of sand, the firing-pin at first did not come in contact with the cartridge, but did after several trials. Arm worked stiffly, and with a grating noise. On examination sand was found in the receiver, in the notches of the tumbler, among the pieces attached to the guard-plate.

VII. Arm subjected to the salt-water test, and four shots fired. Arm did not cock at first every time the breech was entirely opened, but did after working it some time. Extractor started the cases, but did not draw them from the chamber.

VIII. Arm fired with defective cartridges. No escape of gas from the first and third cartridges. Gas escaped from the second, fourth, and fifth cartridges. The sixth cartridge unlocked and slightly depressed the lever. The upper stud of the safety device was blown off. Heavy escape of gas below the breech-block.

IX. Arm tested for strength, by firing with increased charges. Gas escaped from the breech, and unlocked the lever.

With the exception above, no sign of wear or weakness in any of the parts.

VI.—Ward-Burton Rifle, Figs. 2837 to 2843.

The Ward-Burton rifle is the most perfect and complete breech-loading fire-arm that has fallen under our notice; this fact will be proved in the sequel.

The Ward-Burton Rifle, cal. 50, *sent by W. G. Ward, New York.*

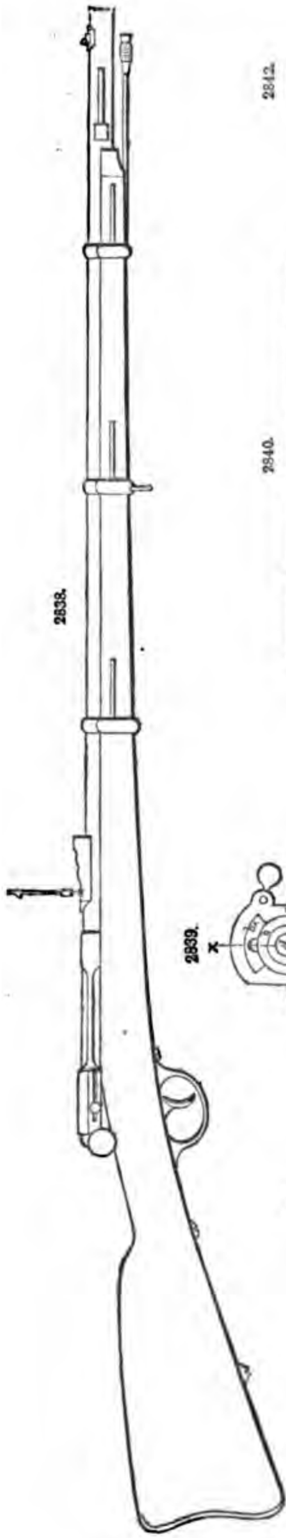
I. Was dismounted, examined, and found to consist of fifty-seven pieces.

II. The arm was fired with the United States' cartridge for accuracy.

III. The arm was fired for rapidity; time, 2 min. 21 sec.

IV. Arm tested for endurance.

First 100 rounds; time, 5 min. Distance between extreme shots, 99 in.; barrel much leaded.



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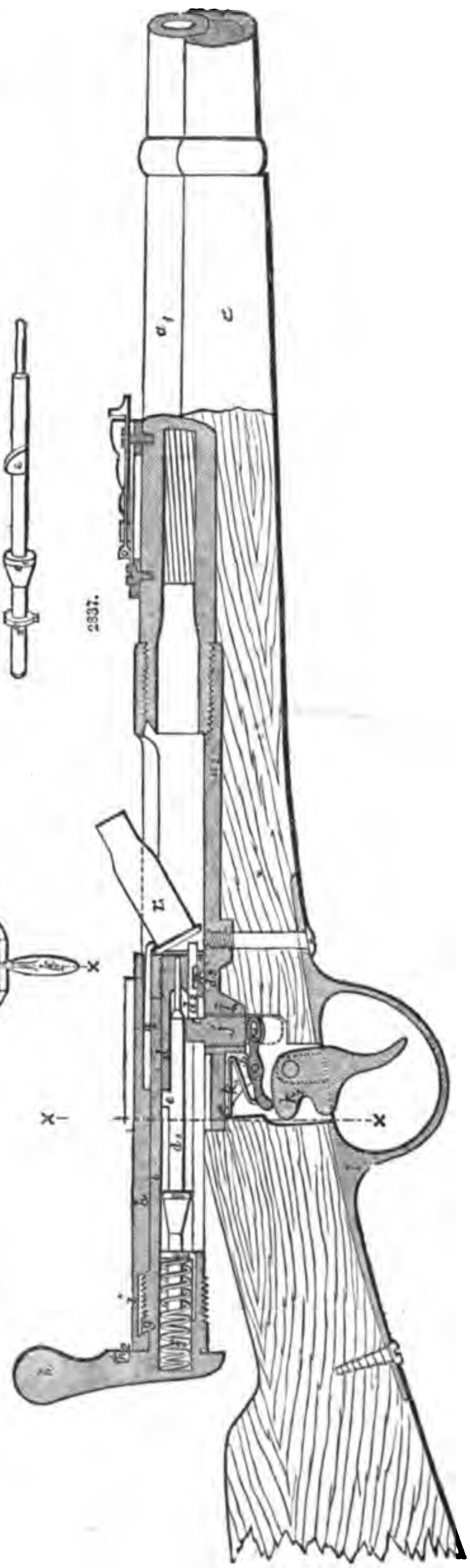

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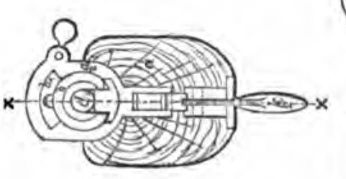

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Second 100 rounds; time, 5 min. 35 sec. Distance between extreme shots, 57 in.

Third 100 rounds; time, 5 min. 10 sec. Distance between extreme shots, 58 in.

Fourth 100 rounds; time, 4 min. 30 sec. Balls wild; gun turned on the river; barrel very much leaded.

Fifth 100 rounds; time, 4 min. 20 sec. Balls thrown on the river.

Arm worked freely; no signs of wear or weakness in any of the parts; cases easily extracted, and thrown clear of the piece.

V. This arm was exposed and fired as prescribed in the fifth test, from April 7 to April 16. Arm rusty, but worked freely; no signs of wear or weakness.

VI. The arm was subjected to the sand test. It worked freely, and very little sand was found in the breech mechanism.

VII. Arm subjected to the salt-water test. The arm was rusty, but worked freely. No signs of wear or weakness.

VIII. Arm fired with defective cartridges. Slight escape of gas from the last three cartridges; piece uninjured.

IX. Arm was tested for strength with increased charges. Piece uninjured; shells were extracted with difficulty.

The Board remained in session, experimenting with and discussing the various arms and other devices presented to them, until the 10th of June, 1870, when they adjourned, after having submitted the following report.

We add the following recommendations and report as a specimen of American official jobbery, which is not far behind the best French or English specimen; what pulled the wires, in this case, we are unable to say.

Office Board on Tactics, Small Arms, &c., St. Louis, June 10, 1870.

General E. D. Townsend, Adjutant-General U. S. Army, Washington, D.C.

General,—The Board of officers appointed by General Orders No. 60, head-quarters of the army, Adjutant-General's Office, August 6, 1869, and whose duties were enlarged by General Orders No. 72, of October 23, 1869, have the honour to submit the following report upon the subject of small arms and accoutrements for the use of the army of the United States;—

Small Arms.

We respectfully refer, first, to the accompanying list of arms, accoutrements, &c., submitted for examination; second, to the daily record of proceedings, giving the plan adopted by the Board for testing the qualities of the various systems of arms submitted, the record of those tests and their results in detail, and, third, an abstract from the record, giving a history of the experiments with each arm. In addition to the recorded experiments, each arm was manipulated and its parts minutely examined by the members of the Board. Our investigations have been limited to the determination of the relative merits of the various systems of breech-loading small arms, without regard to questions of calibre, rifling, ammunition, &c. The main elements of excellence considered are strength, durability, and simplicity of breech mechanism; ease, certainty, and rapidity of firing; and security against injury to arms, or accident from use in the hands of troops. The records of details developed in the various experiments have only been made as incidental to the important tests above enumerated.

The following are the results of the deliberations of the Board, in view of our experiments with and examinations of the several systems of small arms. We have selected the following six systems for infantry musket in the order of relative merit:—(1) the Remington; (2) the Springfield; (3) the Sharp's; (4) the Morgenstern; (5) the Martini-Henry; (6) the Ward-Burton.

For cavalry carbines the order of merit is, in the opinion of the Board, the same as for muskets; but it is regarded as essential for cavalry service that the Remington carbine be so modified as to load at the half-cock.

Only the first three systems named possess such superior excellence as warrants their adoption by the Government for infantry or cavalry without further trial in the hands of troops. Of these three, considering all the elements of excellence and cost of manufacture, the Board are unanimously and decidedly of the opinion that the Remington is the best system for the army of the United States.

Of the breech-loading pistols submitted, the Board have selected the following six in the order of their relative merits;—(1) the Remington single-barrelled pistol, with guard, centre fire; (2) the Smith-Wesson revolver; (3) the Remington revolver No. 2, (4) the Remington revolver No. 5; (5) the Remington revolver No. 3; (6) the Remington revolver No. 4. The Remington is the only single-barrelled pistol submitted. It is an excellent weapon, but should be so modified as to load at half-cock. The Smith-Wesson is decidedly superior to any other revolver submitted. It should be modified as follows, namely: made centre fire; the cylinder lengthened so as to close the space in front of the breech-block, and countersunk to cover the rim of the cartridge; calibre increased to the standard. The main-spring of the Remington arm should be strengthened, so as to increase the certainty of fire; also the plunger should be made to strike more accurately the centre of the base of the cartridge.

The Board respectfully recommend that all small arms be made of the same calibre. Large calibre is regarded as even more important for pistols and revolvers than for arms of longer range. Pistols and revolvers should have the saw-handle so shaped that in bringing the weapon from the holster to an aim it will not be necessary to change the first grasp or bend the wrist. The charge of powder for the pistol cartridge should be increased as much as the strength of the weapon will justify, the limit to be determined by suitable experiments.

It is the opinion of the Board that cavalry armed with the sabre should have one or two single-barrelled pistols as a substitute for the carbine; and that cavalry armed with the carbine should have a revolver as a substitute for the sabre. When time will permit, cavalry troops should be

instructed in the use of all these arms: and all should be kept on hand with small bodies on the frontier, where every variety of cavalry service may be required. In large bodies of cavalry a portion should be armed with the carbine and revolver, and the rest with the sabre and pistols.

The Board recommend that the present dismounted officers' swords be exchanged for a small sword, light, straight, and with metallic scabbard; that company non-commissioned officers' swords be dispensed with—first sergeants to retain the sash: musicians to have a pistol instead of a sword. Light artillery should be armed with the revolver instead of the sabre. All small arms should be made more uniform on the trigger than those now in use. The traction for muskets and carbines should be from 6 to 8 lbs.; that for pistols 4 to 5 lbs. The sights of all rifled arms should be finer than those now in use in the army. In the Remington musket and carbine the comb of the hammer should be made longer, and modified in shape so as to rest more easily on a man's arm while at a support. The face of the hammer should be somewhat rounded, so as to avoid cutting the hand in opening the breech. The Board recommend that the barrels of all small arms shall be browned.

BAYONETS.

The trowel bayonet presented by Lieutenant Rice is believed by the Board to be a valuable substitute for the common bayonet, on account of its great usefulness as an intrenching tool. It also appears to be quite as formidable a weapon as the other. This, however, depends greatly on the conception of the soldier who may be armed with it. The Board, therefore, recommend that 500 trowel bayonets be manufactured and placed in the hands of twenty or twenty-five company commanders whose companies are skilled in the bayonet exercise, and that they be instructed to try them with special reference to the *morale* upon their men. If this test prove satisfactory, the Board recommend that the trowel bayonet be adopted to the exclusion of all others.

CARTRIDGE BOXES.

The following appears to the Board to be the order of relative merit of the cartridge boxes submitted;—(1) Lieutenant J. Butler's pouch; (2) Lieutenant J. Butler's box; (3) General Dyer's pouch; (4) Lieutenant C. L. Best's box; (5) Colonel S. Crispin's box; (6) Lieutenant-Colonel Roberts' box. Neither of those named seem quite to meet the present wants of the infantry soldier. The Board recommend the adoption of a form of pouch, a rough sample of which is submitted with this report, which shall fulfil the following conditions, namely; The pouch to be of soft leather, except its face and cover, to be lined with sheepskin, and to be of the size and shape to contain one packet of cartridges; the package to contain twenty-four cartridges arranged in three rows. The pouch will contain the same number of cartridges emptied into it loosely. Each man should be provided in time of war with four of these pouches, to be properly distributed upon his belt. The cartridges should remain in the original packages until required for use, when one package at a time should be broken and the cartridges emptied loosely into the pouch for most convenient handling. In this manner a man will easily carry ninety-six rounds. In time of peace one or two pouches will be sufficient.

EQUIPMENTS.

The six sets of infantry equipments selected by the Board are arranged in the following order of relative merit;—(1) Penrose's equipments, complete; (2) Baxter's equipments, complete; (3) Sherlock's equipments, complete; (4) Seymour's knapsack; (5) Clifford's knapsack; (6) Mizner's knapsack. The Board do not regard either of those submitted as a satisfactory solution of the important and difficult question of the best form of infantry equipments.

TENT OVERCOAT.

The tent overcoat submitted by Charles Ewing, attorney, is not regarded by the Board as a good substitute for both the shelter tent and poncho, although it would answer well as a substitute for either one or the other for infantry. It would not be a suitable substitute for the poncho for cavalry. In view of these facts, and of the great number of shelter tents and ponchos now on hand, it is not thought advisable to recommend the adoption of the tent overcoat.

PICKET-PIN.

The Board recommend that the picket-pin submitted by H. W. Lyon, blacksmith Third U. S. Cavalry, be adopted instead of the one now in use.

BAYONET-SCABBARD ATTACHMENT.

The Board also recommend the adoption of General Hoffman's modification of the bayonet-scabbard attachment, as being equally applicable and valuable with the common or trowel bayonet.

All other articles submitted to the Board were examined, as well as those specially named in this report and in the daily record, but none except those specially referred to were regarded as of sufficient merit to require special notice.

All of which is respectfully submitted.

J. M. SCHOFIELD, Major-General.
J. H. POTTER, Lieutenant-Colonel Fourth Infantry, Brevet Major-General U.S.A.
W. MERRITT, Brevet Major-General, Lieutenant-Colonel Ninth Cavalry.
JAS. VAN VOAST, Major Eighteenth Infantry.
J. HAMILTON, Brevet Colonel, Major First Artillery.

Ordnance Office, War Department, July 8, 1870.

Respectfully returned by the Adjutant-General.

The opinion expressed by the Board in regard to the relative merits of the several breech-loading systems for small arms is not wholly concurred in by this bureau, and is not, it is thought, sustained by the record of the proceedings which accompanies this report, which shows that serious defects existed in the Remington arms, not observable in the Springfield or the Sharp's, such as frequent failures to explode the cartridges, occasional sticking of the empty shell in the chamber, and the difficulty of moving the hammer and breech-block after firing with heavy charges. The first two of these defects, and also the objection arising from the arm being loaded only at full-cock, have been brought to the notice of this bureau by the commanding officers of all companies using this arm. These defects show that the Remington arm should not be adopted before being thoroughly tested in service.

I agree with the Board that the Remington, the Springfield, and the Sharp's systems are decidedly superior to all other systems which have been brought to their notice, and I recommend that 1000 muskets and 300 carbines be prepared according to each of the three systems, and issued for comparative trial in service; companies of infantry and artillery to have an equal number of muskets of each system, and companies of cavalry an equal number of carbines of each system; monthly reports on the comparative merits to be made regularly to this bureau by company commanders, during a period of not less than twelve months after their first introduction into service, upon forms to be furnished by this bureau, which reports, at the end of twelve months, to be laid before a Board of officers, to be appointed to select a breech-loading arm for adoption by the War Department for the military service. This department is now making the Springfield musket, and is preparing to make the Remington musket for the navy; and it can readily have some of the Sharp's rifles on hand converted into muskets.

I recommend that authority be given to this bureau to purchase 1000 Remington single-barrel pistols, calibre 50, and 1000 Smith and Wesson revolvers of same calibre as our army revolvers (as recommended by the Board), and to have 1000 Remington revolvers altered after the plan of revolver No. 2; these pistols to be issued for comparative trial in service, as in the case of the muskets and carbines. If the revolver is to be retained in service, as I believe it should be, I do not think that the calibre should be increased to 50, which is the established calibre for muskets and carbines.

The recommendation of the Board that the barrels of all small arms be browned is not concurred in at this time. The Ordnance Board in 1868 recommended that "the sense of the army at large be ascertained in regard to browning arms in the hands of troops," and steps to that end have been taken, resulting in conflicting opinions from the field. Recently a Board of officers recommended that some arms should be plated with nickel and tried in service, and measures have been taken by this department in that direction. A limited number of arms might be browned, as recommended by the Board, and tested in service with other arms. It is recommended that 500 trowel bayonets be made and issued, as recommended by the Board. The recommendation in regard to cartridge boxes is concurred in, and it is recommended that a small number of each kind be procured and issued to troops for comparative trial. The recommendations in regard to picket-pins and bayonet-scabbard attachments are concurred in, so far as they apply to future fabrications and purchases. All other recommendations which relate to and affect this department are concurred in.

A. B. Dyer, Brevet Major-General, Chief of Ordnance.

Head-quarters of the Army, July 12, 1870.

Respectfully submitted to the Secretary of War, concurring fully with the report of the Board.

W. T. Sherman, General.

The recommendations of the Chief of Ordnance are approved by the Secretary of War, July 16, 1870.

Edward Schriver, Inspector-General.

The pious ardour of a political bishop, the patriotism of a well-paid official, or the extravagant views of an ordinary visionary inventor, may be readily exposed and moderated or damped by the application of a little sound reasoning, or by a trifle of common sense; but the bumptious pretentions of the inventor of a breech-loading fire-arm cannot be quenched,—they are irrepressible. The gun inventor requires but a smattering knowledge of mechanics; indeed, he only requires to know how the old gun-lock was formed, and how operated to strike a spark by the action of flint upon steel; this old device, so well adapted to effect the purpose for which it was designed, he generally retains to effect a dissimilar purpose, namely, to explode the *fulminate of mercury*, of which we will speak presently.

Out of every 100 men taken at random we have estimated that 54, at least, have contrived a breech-loading fire-arm: to those of the remaining 46 who are not driving a wedge on some War Office, our remarks are addressed.

To obtain the full advantages from a breech-loading fire-arm, the following qualifications, marked A, B, C, &c., are indispensable.

(A). The arm should be light, strong, serviceable, cheap, and readily made.

(B). The breech action simple and easily understood; the combined pieces easily taken apart, to effect cleaning or repairs, and afterwards easily united without the use of tools.

(C). The parts of the breech subject to motion should be well protected from sand, dirt, or wet· capable of long-continued and rapid firing without having but seldom to be cleaned.

(D). The gun should give a low trajectory with light recoil.

(E). The breech should resist squarely and effectively the force of the explosion; it should have its resisting power equally distributed all round the axis of the bore of the barrel.

(F). The breech should be so constructed that, in the event of a damaged cartridge being used,

or in the case of a cartridge bursting, as is often the case, particularly with the Boxer, the escaping gas should be directed off so that it could in no way injure the face or eyes of the soldier.

(G). The breech mechanism should be composed of but few parts, and be of a nature not easily damaged or broken when in use; there should be few, if any, screws to be removed, so that in the event of a casualty the soldier can repair damages upon the field of action without the aid of an armourer.

(H). A breech-loading gun is not perfect that is confined to the exclusive use of a special cartridge; and that cartridge should be fire and water proof,—not to be ignited by exploding of shells, or damaged by damp, rain, or from being transported.

(I). And, lastly, a fire-arm should have the stock in one piece, and not made up of different pieces.

The gun invented by Bethel Burton, with its details represented in Figs. 2837 to 2843, satisfies all the requirements which we have marked (A), (B), (C), &c. Besides, it is impossible, even when firing loose powder, to blow out the movable breech, which is suited to any calibre: the *piece* weighs but 8 lbs., and its penetration is great. The fire-arm represented, Figs. 2837 to 2843, has lately received some important improvements, which Burton has patented; the following description is taken from his specification;—

Fig. 2844 is a side view of the arm, ready to fire.

Fig. 2845 is a longitudinal section of the same.

Fig. 2846, the bolt and cover detached from the screw-support, with the spiral spring and piston projecting from the chamber of the bolt.

Fig. 2847 is the lever which works the bolt, with the screw-support attached.

Fig. 2848 is a front view of the same.

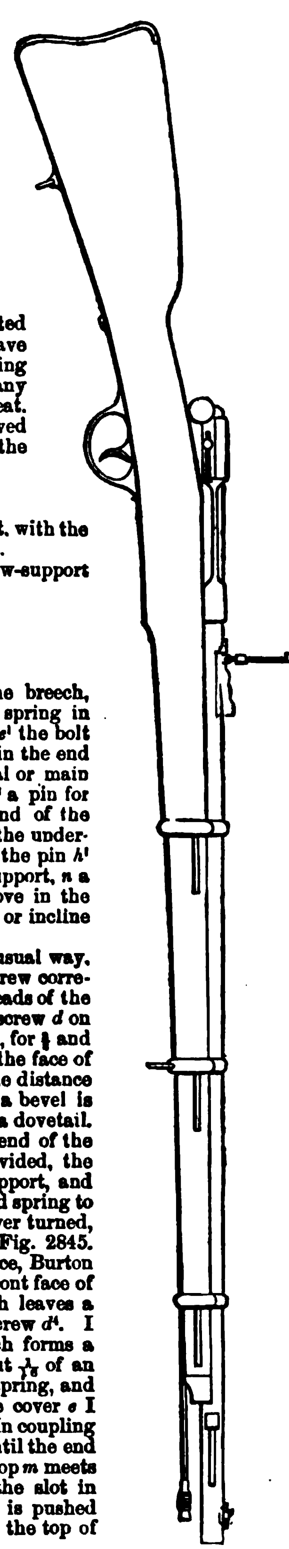
Fig. 2849 is a front view of the bolt.

Fig. 2850 a view of the piston.

Figs. 2851 to 2856 are sections of my improved cartridge.

In describing the parts, *a* is the stock, *b* the barrel, *c* the breech, *d* the screw-support, d^1 the lever attached thereto, d^2 the spiral spring in the lever between the pin d^3 and screw d^4, *e* is the cover and e^1 the bolt in one piece, *f* the piston-rod, f^1 a rib on the piston, f^2 a groove in the end of the piston, f^3 the finger or sear, f^4 the trigger, *g* the spiral or main spring, *h* the extractor, h^1 the pin for ejecting the cartridge, h^2 a pin for fastening in the extractor, *i* a groove in the breech at the end of the barrel, i^1 a hole through the breech into the groove, *j* a bevel on the underside of the front end of the bolt, *k* the position of the hole for the pin h^1 in the bolt, *l* the trigger-spring, *m* a stop-pin in the screw-support, *n* a groove in the screw-support in which the rib f^1 works, *o* a groove in the finger f^3, and *p* a groove in the after-part of the cover *e*, *q* a cam or incline on the coupling or end of the bolt e^1.

The breech is bored out and secured to the barrel in the usual way, and in the rear end of the breech there is formed a sectional screw corresponding to the one on the screw-support *d*; the whole of the threads of the screw in the breech are removed for $\frac{3}{8}$ and $\frac{1}{16}$ of an inch. The screw *d* on the support, Fig. 2847, is not cut close up to the face of the lever, for $\frac{3}{8}$ and $\frac{1}{16}$ of an inch, but is left solid. A groove is made close up to the face of the lever, and down to the diameter of the bolt, and one-half the distance from the face of the lever to the screw *d*, on the edge of which a bevel is made to fit a corresponding bevel *p* in the cover *e* which forms a dovetail. The screw-support *d* is bored out, as seen in dotted lines; the end of the bolt is turned down to fit; the thickness of the metal being divided, the strength of both is equal. A hole is bored out in the screw-support, and into the lever same size as the hole in the bolt, for the piston and spring to work in; the parts are then pushed into each other, and the lever turned, when they are firmly united together in the manner seen in Fig. 2845. In order to prevent the lever from turning until in its proper place, Burton says, I make a hole in the lever to within $\frac{1}{16}$ of an inch of the front face of the lever. I then make an oblong hole, clear through, which leaves a shoulder on the inside. In the other end of the hole I fit a screw d^4. I make a pin d^3 to fit in this hole by filing off two sides, which forms a shoulder or head on the pin, the head of which I make about $\frac{1}{16}$ of an inch, and place the pin in the hole; I then put in the spiral spring, and the screw which keeps them in place. In the rear end of the cover *e* I make a slot in which the point of the pin d^3 can readily enter. In coupling together the bolt and screw-support the pin d^3 is pushed back until the end of the cover *e* comes against it. The lever is turned until the stop *m* meets the side of the cover *e*, the point of the pin d^3 then enters the slot in the cover and prevents the lever from turning until the bolt is pushed forward when the point of the pin d^3, which projects above the top of



2844.

the cover, strikes against the end of the breech at c, and is pushed back and out of the slot in the cover e, which allows of the lever turning, and uniting the sectional screw-threads of the breech with those on the screw-support, which support the bolt against the explosion of the charge; it is then in the position seen in Fig. 2844. When the lever is turned for the purpose of withdrawing the bolt, the pin d^2 immediately enters into the slot of the cover as before. The bolt e^1 is bored out to receive the piston, as indicated by dotted lines; on the end of the bolt at q an incline or cam is cut on which the point of the rib f^1 of the piston works. The rear end of the rib f^1 enters the groove n in the screw-support when the latter is united to the bolt; when the lever is turned, the rib f^1, being in the groove n, causes the piston to turn with the lever, and the point of the rib to turn up the incline or cam q, compressing the spring and forcing the piston back, so that the face of the piston at f^2 does not come in contact with the finger f^3 until the bolt is pushed forward, and the sectional screws commence to engage in each other. The pressure of the spring upon the piston is then transferred from the cam on to the finger, consequently in opening or closing the breech there is no force required. The bolt is allowed to move in and out by means of an oblong slot $\times$, $\times$, in which the end of the finger f^3 works. By making the coupling of the screw-support, with the bolt, behind the finger, I do away with the necessity of a cross-slot to allow the bolt to work on the finger, by which I strengthen the bolt very materially. I strengthen the bolt additionally by the cover and bolt being in one piece, the cover serving for a

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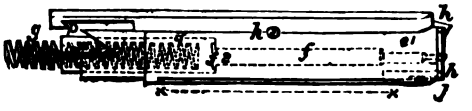

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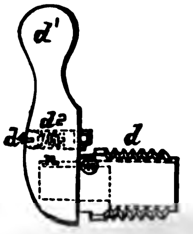

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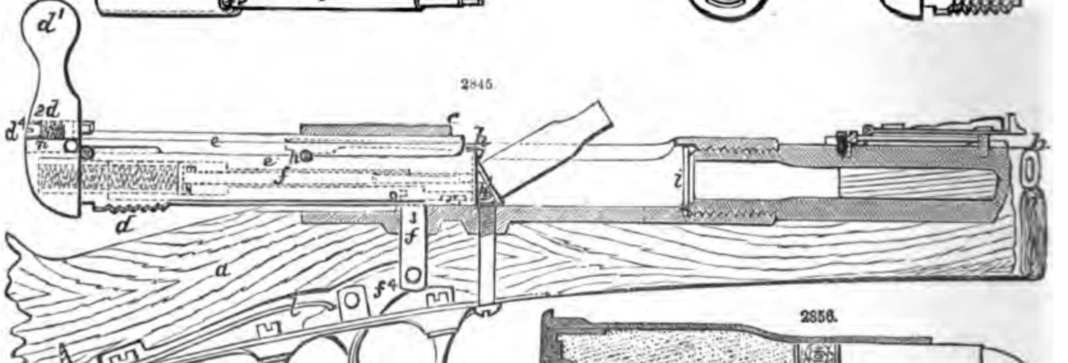

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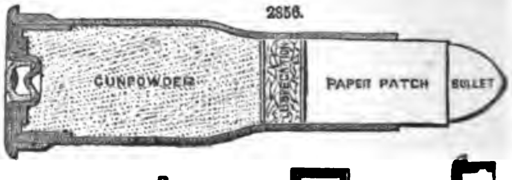

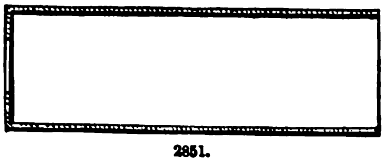

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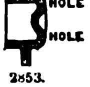

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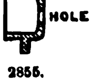

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2852.

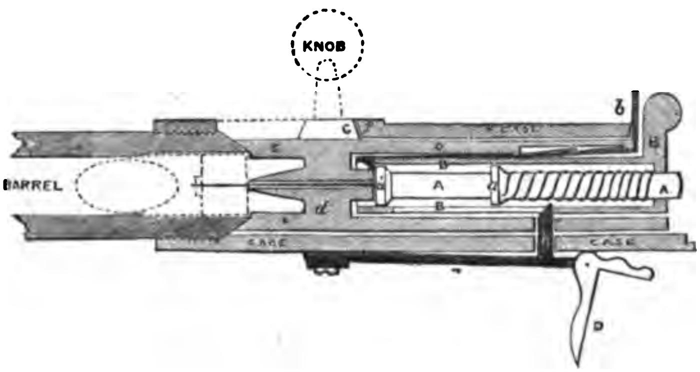
2854.

strap in keeping together the bolt and screw-support. In the cover from h to h^2 I make a hole, as seen by dotted lines; I take a wire the size of the hole and form an extractor, a cross-pin h^2 in the cover e passes partially through the extractor and retains it in place. The pin h^1 being longer than the hole in which it works, projects into the slot $\times$, $\times$, so that when the bolt is pulled sharply out the end of the pin h^1 strikes against the finger f^3, is driven forward, strikes the head of the cartridge, and expels it from the chamber of the breech, as indicated in Fig. 2845. Upon the pin h^1 there is a flat, and in the under-side of the bolt there is a set screw, the point of which passes up and on to this flat, on the pin h^1, allows the pin to move in the hole, but prevents it from coming out. The breech is formed so as to allow the bolt and cover to pass in and out; a strap running from c to h, Fig. 2845, passing over the cover, gives the necessary strength. An opening is cut in the breech in front of the strap to allow access for a cartridge in and out of the chamber of the breech, which opening is filled up by the cover e when in place, see Fig. 2844. In order to prevent

the arm from being fired until the bolt is entirely screwed up, I groove the end of the piston, and into this groove I cut an opening the thickness of the finger at f^3, and on the finger f^3 at o I cut a groove corresponding to the groove in the piston, which engage each other when the bolt is pushed home and the lever turned into the position seen at Fig. 2844. The opening in the piston f^2 is then brought opposite the finger f^3, the finger is then free to be pulled down by the trigger f^4. The piston is then released and is forced forward by the spiral spring g delivering a sharp blow on the cap; this blow ignites the fulminate and fires the charge. In order to carry the arm with safety when loaded and the breech closed, a bolt on the outside rear-end of the breech, resembling the bolt of a door, is made to enter a hole in the lever, which prevents the lever from turning, and while in that position the tongue and groove on the finger f^3 and piston f^2 engage each other, and prevent the possibility of firing the arm. To fire the arm remove the bolt out of the hole in the lever, turn the lever until the screw-support is entirely screwed up, and the arm is again ready to fire. The safety against premature discharge of the arm is not depending on the tongue and groove on the finger and piston; the end of the rib f^1 on the piston would come in contact with the cam q on the bolt before the point of the piston struck the cap, should the trigger be pulled before the breech-bolt was entirely screwed up, which makes the arm doubly safe. Should damaged cartridges be used, in order to prevent gas-escape from coming in the face and eyes of the person firing the arm and from clogging the bolt, thereby preventing its free action, I make a groove i in the breech at the end of the barrel. Through the breech I make a number of holes into this groove, as seen at i^1, Fig. 2844, the gas escaping from the damaged cartridges enters this groove i and out through the holes i^1 in the breech. I form a lip on the end of the barrel, Fig. 2845, which I bevel off. I also bevel off the under-side of the bolt j, as seen at Figs. 2845, 2846, and fit the end of bolt close up to the end of the barrel. The bevelled lip on the barrel allows the cartridge when placed in the chamber of the breech to slide into the chamber of the barrel by the forward motion of the bolt, without the necessity of entering the cartridge by hand into the chamber of the barrel, which very much facilitates the loading of the arm. The end of the bolt being recessed forms a support for the head of the cartridge, and prevents it from dropping down from the hook of the extractor while it is being pulled out of the chamber of the barrel, and expelled therefrom by being struck by the pin h^1 in the bolt in the manner described. I, says Burton, make my cartridge case with the base thereon of felt by one and the same process, after the manner of making felt hats, or by any other suitable means; the base being formed smooth and even can be more securely riveted to the metal base, Fig. 2854, than though the end of the case was turned round to form a base: the case may be made of sheet brass or other metal if desired. The rivet, Figs. 2853 and 2855, is made of brass or other suitable metal, Fig. 2853, to form an anvil, but the rivet, Fig. 2855, may be used with a loose anvil if preferred. In putting together the different parts of the cartridge, I place the rivet, Figs. 2853 or 2855, in the metal cup, Fig. 2852, and solder them together to prevent the gas escaping between them, and place them in the cartridge case. I place the base or head, Fig. 2854, on the outside, and turn the ends of the rivet over, riveting the whole firmly together, in the manner seen at Fig. 2856.

The Prussian Needle-Gun, Fig. 2857.—This fire-arm does not possess in a high degree the qualifications (A), (B); it possesses (I), but is totally deficient in (C), (D), (E), (F), (G), (H). A is the needle-bolt furnished with projections $a\ a'$; the hinder part passes through a spiral spring.

2857.



B B is the lock for drawing the needle-bolt back; it is in the form of a little tube with a projecting *thumb-piece* at one end, and a little tooth or catch (catching the projection a' of the needle-bolt) at the other; it is, moreover, held in its place by the locking spring b, but can be drawn back when b is pressed down.

C C is the chamber, also tubular, in which is fixed the needle-guide d. This chamber slides backwards and forwards in the outer case, by an action precisely similar to a street-door bolt, and it is furnished on the outside with a knob or handle by which to move it, bolt-fashion, a slot being cut lengthwise in it to allow it to pass the catch h. Its bevelled or conical end exactly fits the corresponding bevelled or conical end of the barrel, and it is forced into close contact with the latter by a sidewise motion of the knob, which motion, by thrusting the base of the knob c against the slightly inclined edge f of a slot in the outer case, jams the two bevelled surfaces together, and thus tightly closes the breech.

D is the trigger acting upon the spring g, and thus upon the catch h. The upper surface of the

trigger's horizontal arm takes its purchase against the under-side of the case, and is furnished with three knuckles or points of pressure; according as any one of these knuckles is pressed against the case (by pull upon the trigger), so will the catch *h* be drawn down to a greater distance. The first one is in bearing when the gun is out of use, or immediately after firing: when the second or middle one is brought to bear, the catch *h* is drawn down sufficiently to allow the needle-bolt shoulder *a* to pass over it; when the third is brought to bear, *h* is so far withdrawn that the whole of the lock-tube B B will pass over it, so that a soldier can, if necessary, disable his gun in a moment; if he has to retreat, leaving his gun behind him, he merely pulls the trigger very hard and draws B B out by the thumb-piece, and he leaves behind him an empty, useless barrel.

The various parts are thus manipulated in the process of loading and firing;—

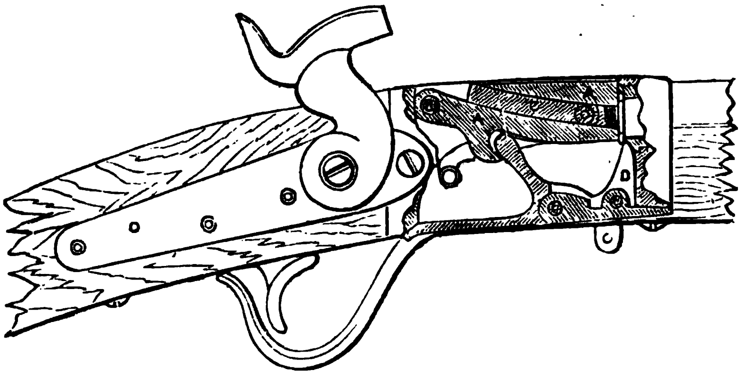
First, the thumb is pressed upon the spring *b*, and by means of the thumb-piece the small lock-tube is drawn back, pulling with it—by means of the little tooth at the opposite end—the needle-bolt, till the shoulder *a* is caught behind the trigger-catch *h*. Then, by pulling the *knob* a little on one side, and at the same time pushing it towards the butt-end of the stock, the chamber C C, with the needle-guide, is slid back, and a clear space is left in that part of the case which is in our drawing occupied by the needle-guide. Through the opening thus made the cartridge is inserted into the end of the barrel, as shown by the dotted lines in the diagram. The chamber is then bolted up again, and the thumb-piece (and so the lock) is pushed forward to its original position. The position of things is then just as shown, with the exception that the needle-bolt, and with it the needle, is held back by the shoulder *a*, catching against the trigger-detent *h*, the spiral spring being of course compressed or in tension. The gun is then ready for firing, the trigger is pulled, *h* is drawn down, and the spring, released, darts the needle through the guide into the cartridge, the blunt end of the needle sharply striking the fulminate and thus igniting the charge.

The barrel of the gun is, in the latest pattern, 32 in. long and $\frac{6}{10}$ of an inch bore, the breech end being widened out to admit the cartridge easily: and it is rifled with four grooves, $\frac{3}{100}$ of an inch deep, the rifling taking one turn in 28¼ in. The total weight of the gun, without the sword-bayonet, is 10¾ lbs.

The chief objections to the needle-gun are doubtless the danger attending the transportation of its paper cartridge, and the delicacy and complication of its mechanical arrangements. The cartridge, unlike the metallic, does not assist in any way to prevent the escape of gas breechwards, so the junction of the chamber-closer or breech-bolt with the barrel must be a perfect mechanical fit, like the safety-valve of a steam-boiler. If a little sand were to get into the joint, an injurious escape of gas would be inevitable.

The Peabody Gun is represented in section, Fig. 2858. A A is the breech-block hinged on the pin B; C is the pin, or striker, which transmits the blow from the hammer to the cartridge, and which is

2858.



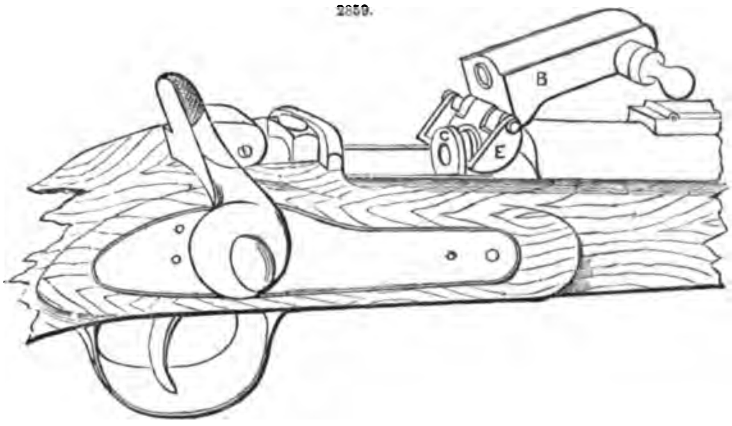
The Peabody Rifle.

capable of a small sliding motion, determined in amount by the pin passed through the oval hole O. In order to open the breech, the trigger-guard is drawn down, by which the breech-block A is depressed, and, catching on the lower part of the elbow-lever D, jerks out the empty cartridge case. By cocking the piece, inserting a fresh cartridge, and pulling up the guard-lever, the gun is again ready for firing. This arm is very deficient in the qualifications (A), (B), (C), (E), (G), and (I).

The gun of Albini and Braedlin, Fig. 2859, is on the Mont Storm system, calibre 0·462 in., adapted for central-fire cartridge. Breech arrangement put on as a shoe. The piston or striker passes through the longitudinal axis of the breech-block, and receives the blow of a horizontal bolt worked by the lock. The extractor consists of two simple forks hinged on the pin of the breech-block, a projecting catch on the back of the fork meeting a similar projection on the block, which, in being turned back, acts as a lever to extract the empty cartridge case. Ammunition: special cartridge, length 3·4 in., weight 689 grains; bullet cylindro-conoidal, with a basal cavity packed with chopped blotting-paper, weight 480 grains: charge of powder 68 grains. Weight of sixty rounds packed, 6 lbs. It will be seen by a reference to Fig. 2859 that the rifle is a combination of the Mont Storm and Snider systems, the arrangement of the extractor being the chief novelty. The breech-block B is here shown open, and the cartridge extractor E in the act of drawing the empty cartridge C. It possesses one or two improvements on the Snider rifle. For instance, if the cartridge does not go home fully, the breech of the Snider cannot be closed, whilst in the case of

the Braedlin the mere closing of the breech helps to force the cartridge to its place. Again, the axis of the striker is in a line with the axis of the barrel, and thus the cap in the cartridge, being struck more fairly, stands a better chance of ignition, and the protrusion of the exploded cap cannot, of course, prevent the breech from being opened. It is scarcely necessary to remark that this fire-arm is deficient of the qualifications (A), (B), (C), (E), (G).

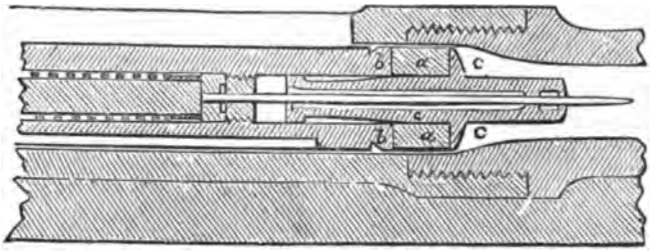
2859.



The Albini-Braedlin Gun.

The Chassepot Rifle, Fig. 2860, the weapon of the French army. This fire-arm does not possess in a high degree the qualifications marked (A), (B), and is totally deficient in those marked (C), (E), (F), (G), (H) This is a needle-gun. The fulminate is not in front, but in rear of the charge, and is

2860.



The Chassepot Rifle.

contained in an ordinary copper cap. The chief feature of the invention, however, consists in the contrivance adopted for preventing the escape of gas breechwards. The hermetic closing of the breech parts is obtained by the instantaneous compression, under the action of the explosion, of a vulcanized caoutchouc washer interposed between the front face of the breech-bolt and a flange, or shoulder, upon the needle-guide. The needle-guide being movable, and the front face of the bolt being fixed, the india-rubber washer is nipped between them. The washer and the flange or shoulder are of a little less diameter than the breech in which they are fitted, so as to facilitate their play therein, but the diameter of the front face of the breech-bolt is, as nearly as possible, equal to the inner diameter of the breech. When the explosion takes place, the pressure transmitted by the movable needle-guide to the washer is such, that the latter is compressed sufficiently to close hermetically the rear end of the barrel and thereby prevent all gas-escape. After the charge is fired, and the pressure removed, the washer, by virtue of its elasticity, returns to its natural position. The ring or washer is composed of three layers of different degrees of hardness, the two outward layers being of much harder substance than the centre one, so that on being pressed the intermediate layer, which is perfectly elastic, expands. A reference to Fig. 2860 will explain the nature of this breech-closing arrangement. The india-rubber ring *a* is compressed by the needle-guide C between the washers *c*, *b*, when the charge is ignited, and is therefore forced to fill the barrel in which, in its normal state, it is a loose fit.

The following particulars relate to the Chassepot rifle;—

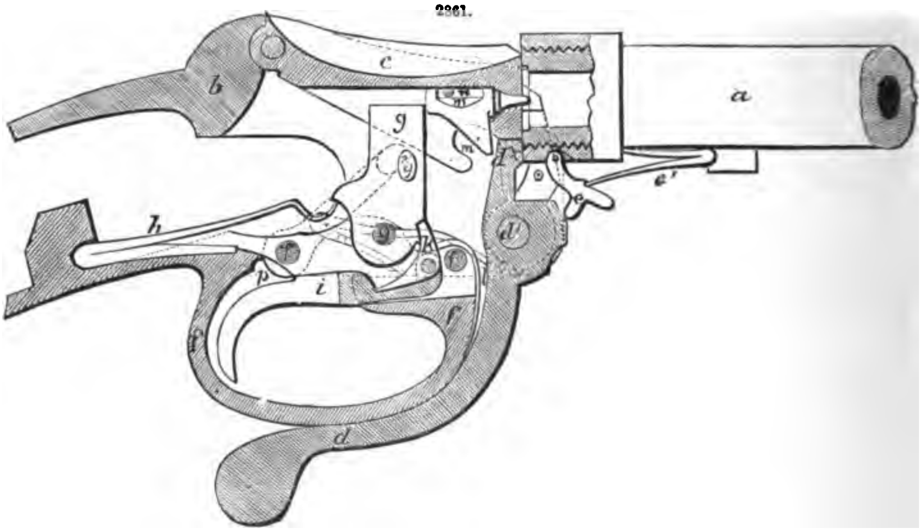
	French measurement.	English measurement.
Weight..	4 kilos. 50 grammes	8 lbs. 14 ozs. 13 drs.
Calibre	11 millimètres	·433 in.
Range	1000 mètres..	1094 yds.
Weight of cartridge ..	31 grammes	478·4 grains.
Weight of ball	24 „	370·4 „
Weight of charge ..	5½ „	84·8 „
Number of grooves ..	4	

The Martini-Henry Rifle, Fig. 2836. in which *a*, barrel; *b*, body; *c*, block; *d*, block axis-pin; *e*, striker; *f*, main-spring. *g*, stop-nut *h*, extractor; *i*, extractor axis-pin; *j*, rod and fore-end holder; *k*, rod and fore-end holder-screw; *l*, ramrod. *m*, stock fore-end; *n*, tumbler; *o*, lever; *p*, lever and tumbler axis-pin; *q*, trigger plate and guard; *r*, trigger; *s*, tumbler-rest; *t*, trigger and rest axis-pin; *u*, trigger and rest-spring; *v*, stock-butt *w*, stock-bolt; *x*, lever catch-block spring and pin; A, locking bolt: B, thumb-piece

With regard to the so-called Martini gun, better known in the United States and Canada as the Peabody gun—in which places as well as in Switzerland, with this arm numerous accidents have occurred, and all trials with it have been unsatisfactory—the Woolwich committee on small arms, after two years' investigation, we should have said dodging, at great expense to the nation, recommended its adoption as the best arm for the British soldier. Without hesitation we proclaim this truth, the Martini rifle is the most costly and difficult arm to manufacture, and it is deficient in every essential point from (A) to (I), with the exception of (D) and (F).

Westley Richards' Rifle.—Fig. 2861 is a longitudinal section of a portion of a breech-loading fire-arm constructed on the Peabody system.

2861.



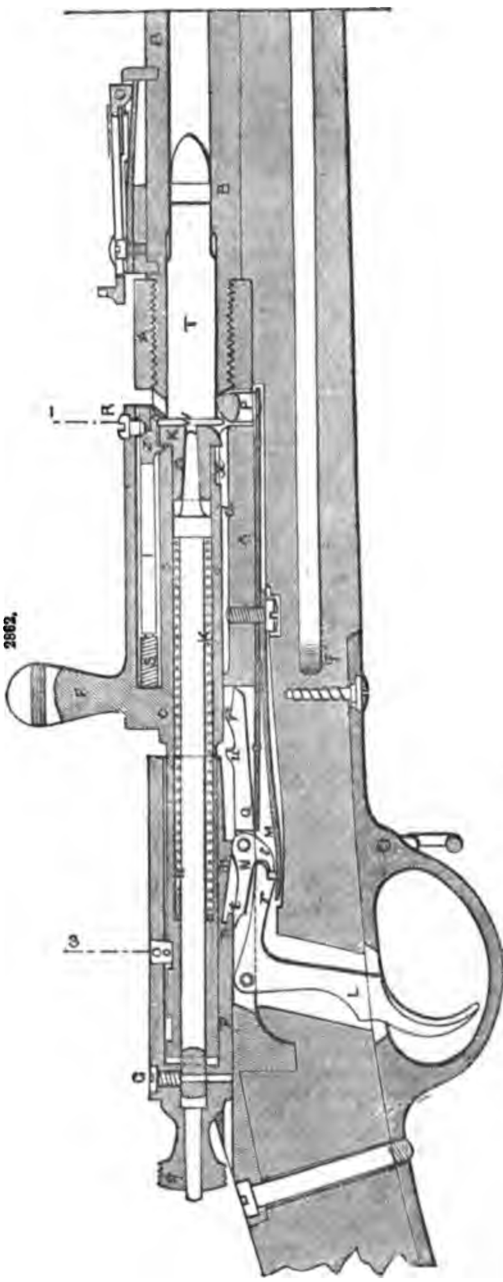
a is a portion of the barrel, and *b* the body or frame into the socket at the fore part of which the barrel is screwed; *c* is the drop-block jointed at its rear end to the body; *d* is the hand-lever for supporting and working the breech-block, it turns on a pin or axis a^1 carried by the side cheeks of the body; *e* is a small lever which by the spring e^1 is caused to bear on an incline on the boss of the hand-lever, giving the hand-lever a tendency to remain at either end of its course; *f* is the trigger plate and guard, it is fixed to the side cheeks of the body by pins f^1 and f^2; it carries the hammer *g* on the axis g^1, the main-spring *h*, the trigger *i*, and the sear *k*, which, as is shown, is mounted on the same pin as the trigger. The main-spring may either press directly on the hammer or act upon it through a swivel or link. The sear-spring *l* is also carried by the trigger plate and guard; *m* is the striker capable of sliding in a straight line in a hole bored and slotted for it in the breech-block *c*. The stop-pin *n* limits the motion of the striker in a backward direction and prevents it escaping from the block; m^1 is a projection on the striker with which, in opening the breech, the inner end or arm $d^{\times}$ of the hand-lever *d* comes in contact, the striker is thus pushed back a short distance, sufficient to retire its nose beneath the face of the breech-block *c*, before the lever acts on the block to cause it to drop. The back of the striker pushes back the hammer until the breech is partly open, and then the sides of the drop-block act against projections g^2 on the hammer and carry it back until the full-cock bent upon it is caught by the sear. On shutting the breech the drop-block and striker return, leaving the hammer retained by the sear. On pressing the trigger, the sear-nose is lifted out of the bent and the hammer delivers its blow upon the striker and the cartridge is fired. *o* is the extractor, and *p* a level bolt for locking the trigger.

Of this gun we have only to add, that its imaginary improvements consist of a confused complication of its parts, and looks like an endeavour to evade the Peabody-Martini system, like which it is deficient in all the qualifications from (A) to (I), except (D) and (F).

The Remington Rifle.—Fig. 2835 is a side view of the breech.

In this rifle there is no essentially novel feature in the stock *a*, barrel *b*, or frame *c*. Remington in his specification observes, "I prefer to arrange the hammer *d* centrally behind the swinging breech-piece *e*, and to form the same with an extension d^1, which serves as a tumbler, and which is provided with notches 1, 2, for the trigger *f* to take into, but if desired a separate tumbler may be used, the hammer being then arranged at the side of the breech. The breech-piece *e* which is curved on its upper surface to allow it to swing down in front of the hammer *d* (or the tumbler) is bored or recessed from the rear to within a slight distance of its front surface e^1 which lies in contact with the cartridge, this surface being perforated at e^2 to form a passage for the needle *g*. The surface e^1 of the breech-piece is quite plain or flat, and closes the breech perfectly without any valve or gas-check such as is ordinarily employed in breech-loading arms when paper cartridges are used.

The needle g is fixed by screwing or otherwise in the bolt or pin h which works in the recess or cavity e^3 in the breech-block e; the said pin is kept back in the proper position to be struck by the hammer by a spiral spring i, and in order that this spring may not occupy any portion of the space in the said cavity in front of the bolt h, and shall leave the same clear for the advance of the bolt when the same and the needle are driven forward, I make the said bolt hollow and insert the spring within the same. By this means the bolt h can be driven forward till its end h^1 is in contact or nearly so with the end of the recess e^3. To allow the bolt h to be thus made hollow, the needle g, instead of being in the centre, is fixed near the periphery of the said bolt and (as I now construct the arm) above the centre of the same. In order that the bolt h may not be driven too far forward the breech-piece at the back of the recess or chamber e^3 is formed to act as a stop to the hammer d. To drive the needle forward the required distance, it is necessary in this arrangement of parts that the end of the hammer should follow the bolt some distance in the recess e^3. For this purpose I form the end of the said hammer with a circular or other shaped piece d^2, which projects beyond the shoulder d^3 and enters the recess, the said piece being of such a length that the bolt and needle are driven far enough forward to effect the explosion of the cartridge before the hammer is stopped. The escape of the bolt or pin h from the recess e^3 is prevented by a screw or pin e^4 which is passed through the side of the breech-piece e, the front end of the bolt being formed with a stop h^1 which will not pass over the said screw. It is desirable that the distance between the centre of the barrel b and the axle-pin j of the breech-piece e should be as short as possible, and for this purpose the circular part e^5 of the breech-piece which surrounds the said axle-pin is made concave at e^6 on the side adjacent to the barrel b. The lower part of the end of the barrel which lies in this concave part e^6 has a portion of its exterior surface cut away at b^1 to make it conform to the shape of the concavity e^6 in the breech-piece. A compact arrangement of parts is thus obtained in which the free movement of the breech-piece is not affected by its close proximity to the barrel." But it is affected when 85 grs. of powder and 480 grs. of lead are used; for, the lower part of the barrel being cut away (to make room for the joint of the breech-block), the force of the explosion presses that part down on the joint of the block, and prevents the block from being drawn or turned back to extract the cartridge by the pressure of the hand; see test IX., page 1471. "The pin j and the hammer-pin k are passed through both sides of the frame c."



2862.

This arm of Remington is greatly deficient in all our requirements marked (A) to (I).

The so-called Berdan gun, Fig. 2862, is merely a clumsy attempt to evade the patents of Bethel Burton. Fig. 2862 is a longitudinal vertical section of this breech-loader taken along the centre line of the barrel. The open part of the breech A which receives the cartridge is provided at its lower part with a cavity d in which the dirt and dust may be received. The extreme faces of this receptacle are provided at f and g with two inclined planes. It may be remarked also that the closing projection b of the movable breech C is on the one hand prolonged in front sufficiently far to afford space for the screw R which secures the cartridge

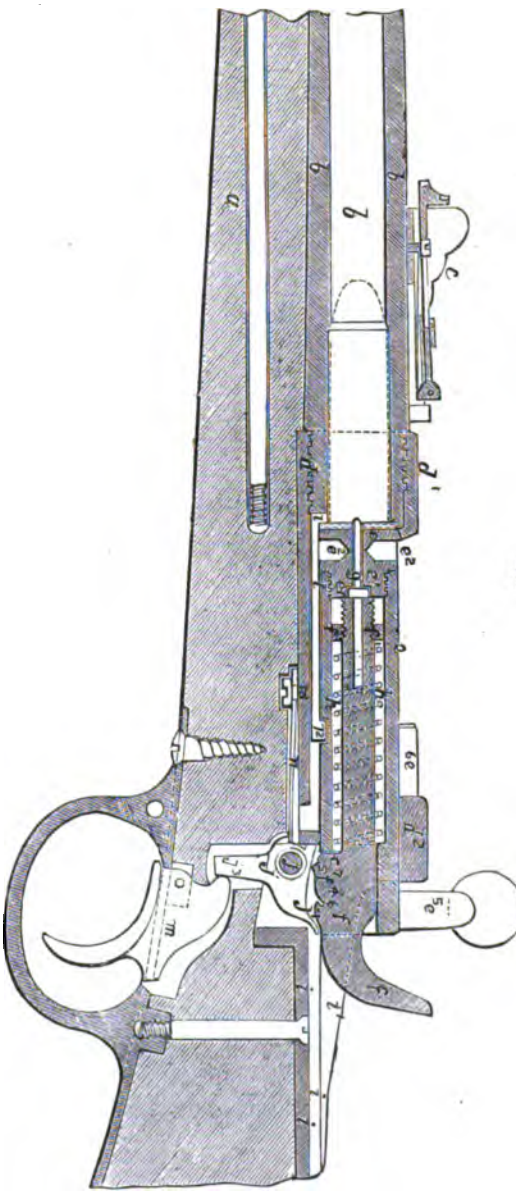
extractor above the hook of the latter, and on the other hand to form a stop for the bolt, which stop shall come in contact with the fixed breech when this bolt is pushed forward. The long collar or socket D which encloses the bolt C is shown of sufficient length to enable the spring H of the striker to be long enough to ensure a regular and certain action.

The trigger-spring M operates on the end *r* of the shorter arm of the trigger, which in its turn transmits its action to the shorter arm *s* of the curved tumbler or lever N. This lever is so constructed as to enter the bottom of the full-cock bent or notch *m* during the forward movement of the latter by reason of the end *t* of the tumbler N being situate above the axis on which the lever itself works. Care has also been taken to provide the half-cock bent or notch *n* with a heel, which prevents the end *t* of the tumbler or lever N from being disengaged therefrom by any manipulation of the trigger L. The rib or projection *p* in which are formed the bents *m* and *n* is cut with an inclined surface, so as to ensure the free play of the bolt C and the entrance of the point *t* into the bents. To the under-side of the breech-piece A there is fixed a blade-spring O, which at one end terminates in a curved surface P intended to facilitate the automatic introduction of the cartridge into the barrel, whilst the other extremity of the spring tends constantly to elevate the piece Q, which is provided with projections *u* and *v*; the projection *u*, Fig. 2862, is intended to restrict or limit the recoil of the bolt C by entering a notch *x* formed on the under-side thereof behind the enlarged extremity K; thus it is simply requisite to press upon the end of the piece in order to remove or detach the bolt or sliding breech as well as the parts connected therewith; the projection *u* serves also by entering the notch *x* to prevent the bolt C from sliding forward and closing the breech when the muzzle of the gun is inclined downwards. The second projection *v* of the piece serves as a stop or obstruction to the flange of the cartridge when it is drawn back by the extractor I, and thus facilitates its automatic discharge from the arm. The extractor I is contained in the closing projection of the bolt C. It is maintained in its place by a screw R, against which it is constantly pressed by a helical spring S disposed at the rear end of the part. The dimensions of the chamber which encloses the extractor are such that the latter may have sufficient play therein to allow it to seize the flange *w* of the cartridge when moved forward with the bolt at the time of closing the breech. In order to keep the catch of the extractor lowered upon the flange *w* during the whole time of opening the breech the upper surface of the catch is formed with an inclination *z* bearing against the screw R, which thus serves to regulate the position of the extractor in its sheath or chamber. Another inclined surface *y* causes the extractor to mount over the flange *w* of the cartridge case T at the moment the catch or claw encounters the flange when forcing the cartridge into the barrel.

We describe this arm, not for its merits, but because it is a good specimen out of the many we have examined, to show how the would-be inventor of a breech-loading fire-arm appropriates to himself the ingenuity of others; such cases fully represent how deficient are our Patent laws, which grant patents for the same inventions over and over again, thus turning the Patent Office into a mock-auction shop, and thus enabling unscrupulous persons to set aside the honest meritorious inventor. This arm is totally deficient in (A), (B), (C), (E), (F), and (G).

Fig. 2863 represents how the parts of J. H. Burton's gun are combined; it is a longitudinal section. *a* shows a portion of the stock; *b*, a portion of the barrel; *c* is the sight; *d* is the shoe in the cavity (between the breech d^1 and the bridge d^2) of which the cartridge is placed. The cartridge is forced into position for firing in the breech end of the barrel by the breech-bolt *e*; this breech-bolt is formed to slide and turn easily in the shoe *d* and its fore end or face or head e^1 is by preference formed of hardened steel or of case-hardened iron and to screw into that end of the breech-bolt. To facilitate the turning of this part e^1 for its removal or replacement it is formed with a series of holes or recesses e^2 in its periphery adapted to receive the end of any suitable pin to act for the time as a lever in turning that piece e^1 for screwing it into or unscrewing it from the main part of the breech-bolt *e*. *f* is the hammer, in the fore end of which is fitted the striking pin *g* for exploding the cartridge and thereby firing the charge, as is well understood; *h* is the hammer-spring, which is of a helical form and rests at one end against the end of the chamber formed for it, as shown in the breech-bolt *e*, and at the other end it rests against the collar f^1 on the hammer, with a tendency to force the hammer forwards with an elastic force. The collar f^1 is formed to screw on to the end of the hammer *f* as a nut, facility for the application or adjustment of which is obtained by the head e^1 of the bolt *e* being movable. The end of the chamber in the bolt *e* thus acts as an abutment for one end of the helical hammer-spring *h*, whilst the nut f^1 acts as an abutment for the other end of it. This collar or nut f^1 is formed to touch the interior of the breech-bolt *e* at parts of its surface, the other parts of its surface being cut away to admit of the air contained in the chamber of the breech-bolt freely passing from one side to the other of this collar as it moves in that chamber with the movement of the hammer. The hammer *f* is formed with a strong fin or projection f^4, which when the parts are in the position for firing is capable of sliding in a longitudinal opening or slot provided for it in the breech-bolt *e*. The lower edge or surface of this fin or projection f^4 also passes into a groove i^1 formed for it in the rear extension *i* of the shoe *d*, or it may be in a plate separate from it. Across the lower edge or surface of this fin f^4 is also formed the full-cock notch 5 and the half-cock notch 6 to receive the nose j^1 of the sear *j*. The breech-bolt at its rear end is also cut away in order that when the hammer is drawn back so that the nose j^1 of the sear enters the notch 5, the fin or projection f^4 is out of the slot in the breech-bolt; the breech-bolt may then be turned partly round by acting on the handle e^5, so as to bring the projection e^6 coincident with the opening formed for its passage in the bridge d^2, and thereby admit of the breech-bolt being drawn back. The projection e^6 on the breech-bolt *e*, when the parts are in position, with its rear end abutting against the bridge d^2, serves to hold the breech-bolt with its face or head e^1 correctly in the breech end of the barrel, and this projection e^6 in connection with the bridge d^2 receives the shock of the discharge. In the turning and subsequent back movement of the breech-bolt the hammer passes from being held by the sear *j* to being held by its shoulder f^7, resting against the rear end of the breech-bolt, by which, although the hammer is held

as it were at full-cock, it is also so held by the rear end of the breech-bolt as to render it impossible for it to be impelled forward prematurely to explode the cartridge whilst the breech-bolt is in any position other than that for firing. The case of each discharged cartridge is after firing withdrawn from the barrel by means of the plate l, which is capable of sliding in a groove formed for it in the lower part of the shoe, and at one end this plate l is formed with a projection l^1 to catch on the projecting edge or rim of the cartridge case, and at the other end it is formed with another projection l^2 to pass into a compound longitudinal and transverse groove formed in the underside of the breech-bolt. The part e^7 of this compound groove is in a line parallel with the axis of the breech-bolt, and at its fore end a shoulder is formed to it by the head or face e^1; this part e^7 is of length sufficient to admit of the breech-bolt being withdrawn some distance before the extractor acts upon the cartridge case to withdraw it, and the momentum thus obtained by the breech-bolt renders the action upon the spent cartridge case more effective to withdraw it in the case of its sticking in the breech end of the barrel. The transverse portion of this groove serves to receive the projection l^2 and admit of the turning of the breech-bolt e when it is fully in its place in the rear or breech end of the barrel. A stop limiting the longitudinal motion of the breech-bolt backwards is thus provided by the projection l^2 on the rear end of the extractor acting in conjunction with the shoulder formed by the movable head e^1 of the breech-bolt, and the rear end or termination of the groove in the shoe in which the extractor slides. The sear j is supported to turn upon an axis j^2 carried by lugs projecting from the under-side of the shoe d. The lever j^3 of the sear is in position to be acted upon by the trigger m, and it is borne upon by the spring n also affixed to the shoe d with a tendency to bear the nose of the sear j towards the hammer in order that the sear may properly engage the tumbler notches 5 and 6 formed on the projecting fin f^4 of the hammer f. J. H. Burton's gun is totally deficient in (C), (E), (F), and is a combination of the Bethel Burton and the Chassepot.


2863

The Snider Gun, Figs. 2864 to 2866. This fire-arm is deficient of the essential properties marked (A), (B), (E), (G).

The mechanism is extremely rude, the breech-block hinges upon a side pin and works backwards and forwards. It is kept in its place by a small spring stud a, Fig. 2866; this stud has been changed from time to time from the breech to the block and from the block to the breech.

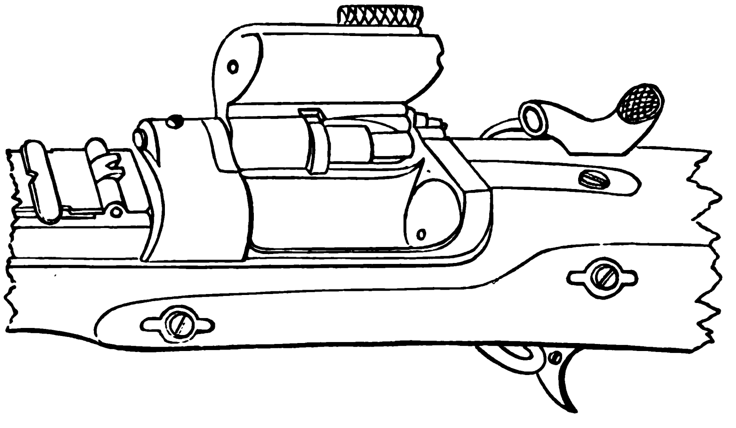
The ignition is effected by means of a small piston or striker, which passes through the breech-block and which when in repose is flush with the face of the block. A blow of the hammer causes it to dart forward about a tenth of an inch into the cap which is fixed, as shown in Figs. 2865, 2866. The piston is returned by a spiral spring. To withdraw the empty cartridge case, a claw or extractor forms part of the breech-block. When the block is withdrawn the empty cartridge is necessarily drawn with it, and by canting the rifle sideways the case is thrown out. The extractor is returned by another spiral spring.

Snider's gun proposed in 1866 is illustrated by Figs. 2867 to 2870.

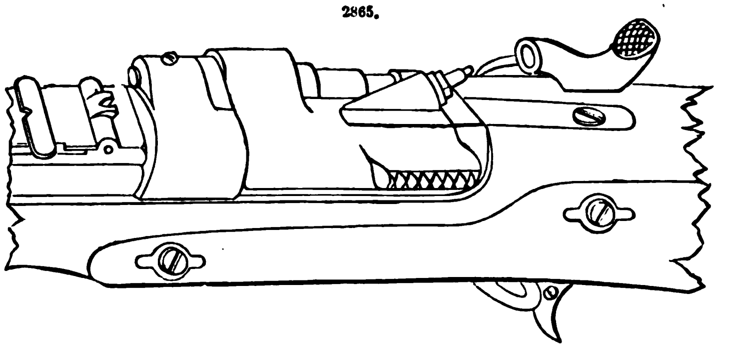
Fig. 2867 is a longitudinal section, and Fig. 2870 a plan of part of the breech. An opening is made at the rear end of the barrel to receive the breech-piece c, or this opening may be in a shoe

into which the barrel is screwed. The breech-piece which occupies this opening is attached to the barrel or shoe *f* by a hinge *e* affixed to its upper portion, surrounding the charge chamber so as to form a covering and admit of space within it for the movement of a draw cartridge *g*, and which is placed and moves in a slot or groove formed therein. This draw cartridge is operated by means of a cog or ratchet *a* on it, acted upon by a corresponding cog or ratchet *b* on the movable part of the hinge *e* which is attached to the breech-piece *c*, so that after a charge has been fired the expended cartridge case will be withdrawn from the charge chamber *d* by the action of lifting or opening the breech-piece *c*, causing the cog or ratchet *b* on the hinge *e* to act on the ratchet of the draw cartridge, and forcing the latter against the head or rim of the cartridge case and thus withdraw it.

2864.



2865.



2866

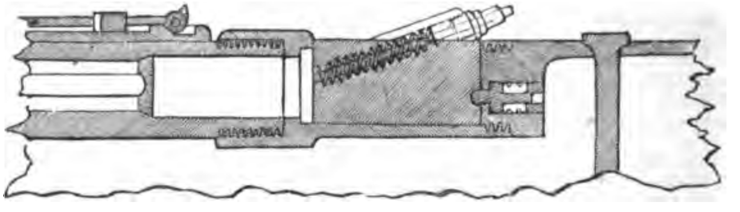


Fig. 2868 is a vertical section through the line *x*, *y*, of Fig. 2867, and Fig. 2869 a similar view through the line *z*, *z'*. When the arm is charged it is locked and retained in place by means, before described, for locking the breech of fire-arms; see Figs. 2864 to 2866.

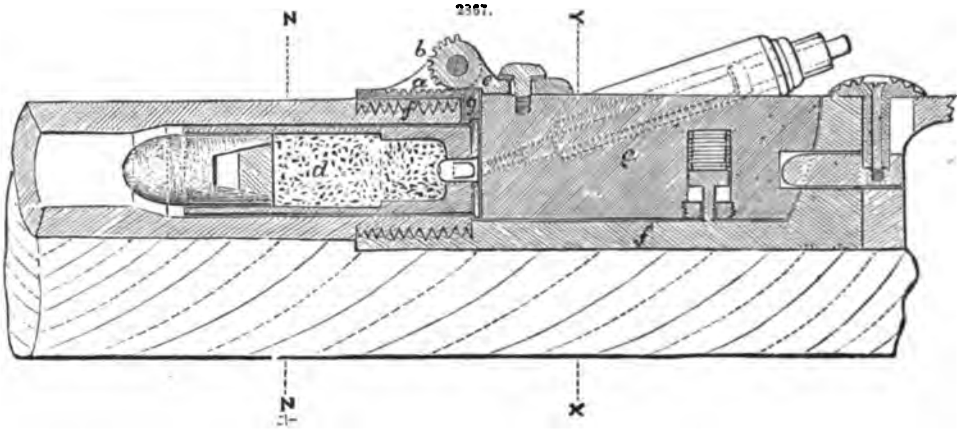
There is a hole made through the breech-support or plug, Fig. 2867. In this hole is placed a self-latching locking bolt. to this bolt is connected a shaft that works in a hole or slot in the tang of the breech-support, for the purpose of opening the breech.

These strictures might be continued to a great length on the vast number of fire-arms that we have examined, but we shorten our task by discarding all such contrivances that lack all our qualifications designated (A), (B), (C), (D), (E), (F), (G), (H), and (I).

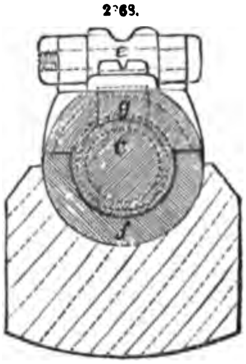
The revolver or pistol, which is the smallest of breech-loading fire-arms, follows suit. From Colt down to Smith and Wesson there is no mechanical novelty worth attention. The revolving pistol comes under two heads, namely, the pocket pistol and the army pistol. Smith and Wesson's improvements over Colt chiefly consist in making arrangements so that metallic cartridges may be

used, indeed we give preference to Colt's system; to Colt is due the merit of perfecting this species of arm, all other pistol inventors only attempt to attain the same end in a more indirect manner and by greater complication

2867.

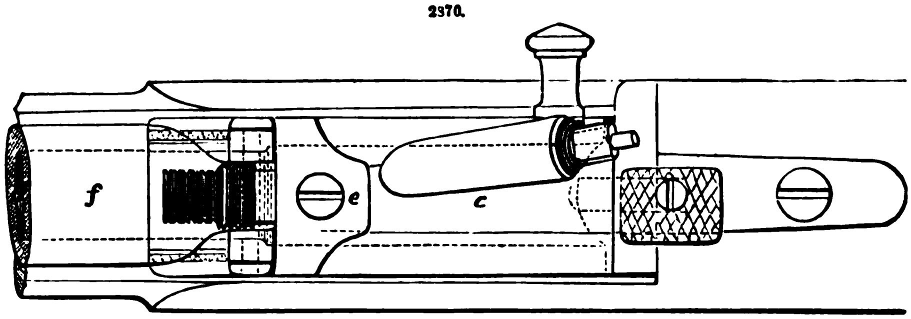


2868.



2869.

2870.

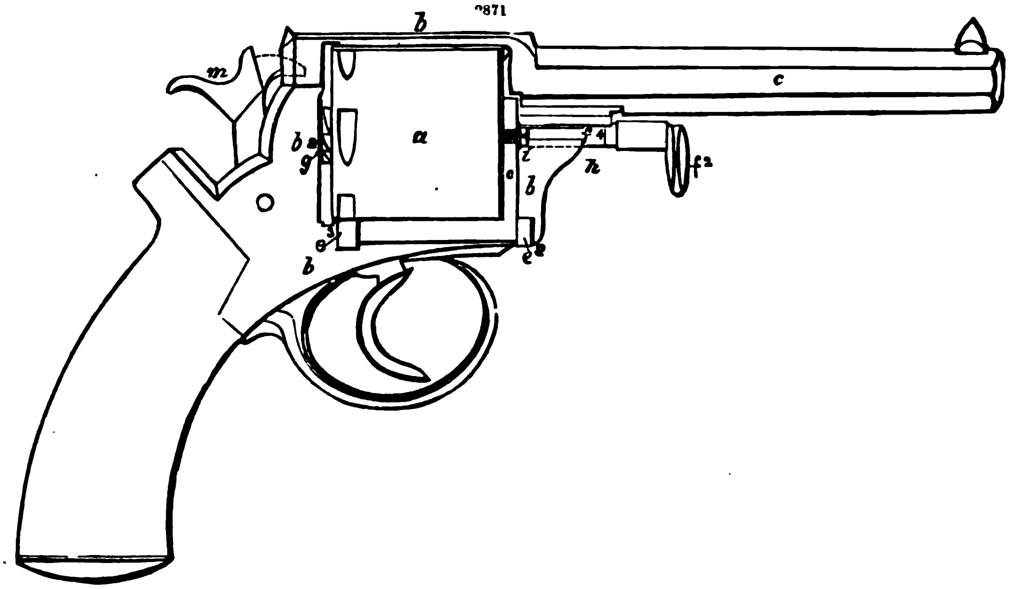


Albini's Revolver.—Fig. 2871 represents in side elevation, and Fig. 2872 in side elevation partly in longitudinal section, a repeating or revolving pistol constructed according to Albini's method of arrangement: Figs. 2873 to 2876 are parts of the same pistol, when detached.

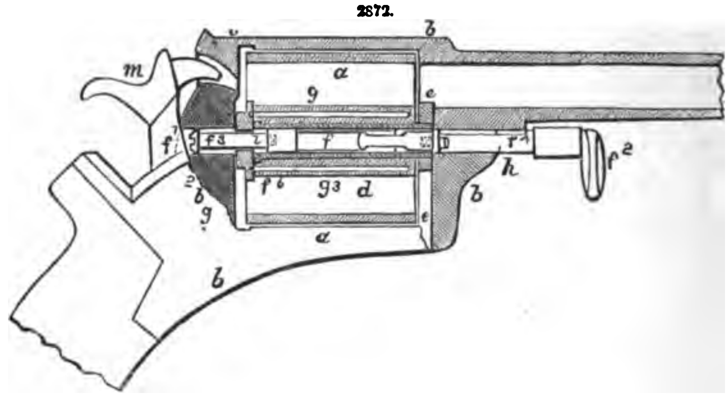
a is the revolving cylinder; *b* is the solid frame of the pistol, and *c* is the barrel; the solid frame and barrel are made in one piece as usual. The cylinder *a* is mounted on the tubular axis *d*, upon which axis the cylinder *a* is capable of revolving to bring each of its chambers in succession in a line with the barrel *c*. The front end of the said tubular axis *d* is carried by the arm *e*, the lower horizontal part of which is jointed at e^2, e^3, to the side of the frame *b*; the axis *d* and arm *e* are shown separately in Fig. 2873. The said arm *e* moves in a vertical plane upon its joint, and the cylinder *a* is by the motion of the said arm capable of being turned out of or into the frame *b*, as illustrated in the drawing. In the tubular axis *d* is a rod *f* by which the extractor *g* is operated and the cylinder *a* locked to and released from the frame *b*, the rod *f* is shown separately in Fig. 2874; the said rod *f* is provided with a thumb-plate or handle f^2 by which it may be moved backwards and forwards in the hollow axis *d*. In the fore part of the frame *b* is a channel *h* in which the front end of the rod *f* works. The hole or channel *h* serves as a guide to the rod *f*, and

assists in locking the cylinder a in its frame. The side h^2 of the channel h is open, to permit of the removal by a lateral motion of the said rod f from the channel h, when the cylinder a is turned out

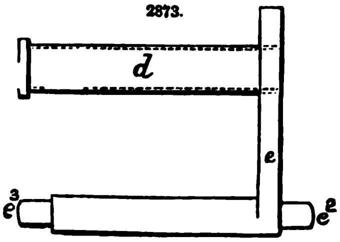
2871



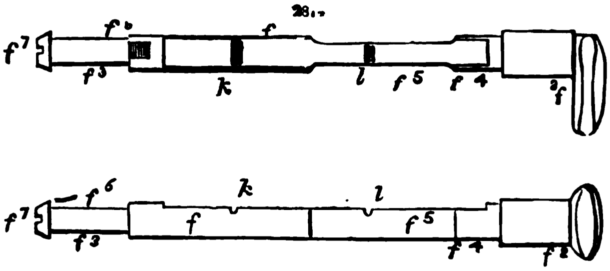
2872.



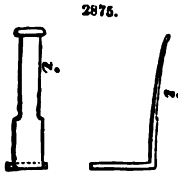
2873.



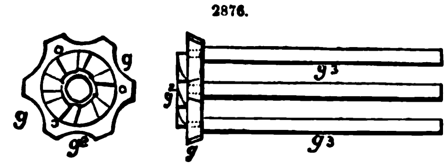
2874.



2875.



2876.

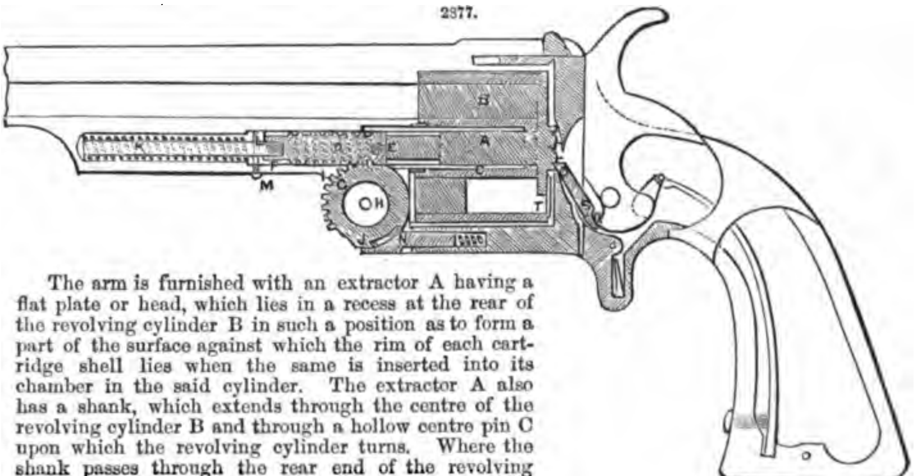


of the frame b on its jointed arm e. When the rod f is pushed forward, its fore end f^4 enters a hole b^2, Fig. 2872, in the back of the frame b, and securely fastens the cylinder in the frame. When

the rod is in this position the rear end f^3 is situated in the channel h, and the said part f^4 prevents the rod being drawn through the lateral opening h^2 of the channel h. When it is wished to release the cylinder a the rod f is pulled towards the muzzle end of the pistol, the front end f^3 of the rod is thereby withdrawn from the hole b^2, and the rear part f^4 is also removed from the channel h, when the cylinder a may be turned outwards upon its jointed arm e. When in the last-described position a cut-away part f^5 of the rod f is brought opposite the lateral opening h^2 of the channel h, and the said rod can pass through the said opening. The sliding motion of the rod f is limited by a spring-top i, Fig. 2875, within the tubular axis d engaging with one or other of two notches or depressions k, l, in the rod f; when the rod f is drawn forward to release the cylinder a, the stop i falls into the notch or depression k; and when the said rod is pushed outwards to operate the extractor, the said stop i drops into the notch or depression l; in either case the further motion of the rod is arrested. The extractor g, Fig. 2876, consists of a notched disk or plate having a ratchet g^2 at back, upon which ratchet the lock acts to propel forward the cylinder a. The extractor is connected to the cylinder a, and its motion transmitted to the cylinder a by means of the guide-rods g^3, g^3, sliding in holes in the said cylinder. The extractor g is pushed outwards from the cylinder a, when the rod f is pushed towards the back of the body by means of a shoulder f^6 on the said rod bearing against the inner face of the extractor, and the said extractor is pushed inwards to its place at the rear of the cylinder when the rod f is drawn towards the muzzle of the pistol by means of the head f^7 on the said rod bearing against the outer face of the extractor. When the parts of the pistol are in the respective positions represented in Figs. 2871, 2872, the said pistol is ready for discharge. After discharge, in order to extract the cases of the exploded cartridges and reload the pistol, the parts are manipulated as follows;—The hammer m is first raised to half-cock, the rod f is next pulled forward by its thumb-plate or handle f^2, so as to withdraw the front end f^3 from the back of the body or frame b, and bring the cut-away part f^5 opposite the lateral opening h^2 in the frame b.

Smith and Wesson's Revolver.—Fig. 2877 is a longitudinal section of this revolving fire-arm· Fig. 2878 is a similar section with the parts of the arm in a different position.

2877.

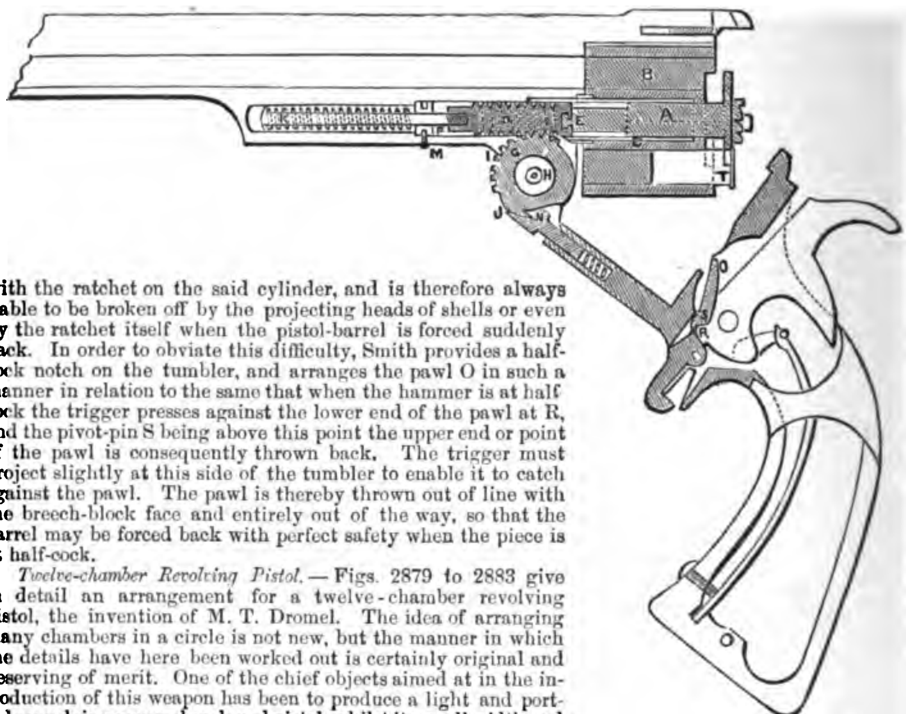


The arm is furnished with an extractor A having a flat plate or head, which lies in a recess at the rear of the revolving cylinder B in such a position as to form a part of the surface against which the rim of each cartridge shell lies when the same is inserted into its chamber in the said cylinder. The extractor A also has a shank, which extends through the centre of the revolving cylinder B and through a hollow centre pin C upon which the revolving cylinder turns. Where the shank passes through the rear end of the revolving cylinder B it is made square, so that it has to turn with the cylinder B when the latter is revolved. To the forward end of this extractor is attached a rack D by a coupling joint E which allows the extractor to revolve without turning the rack D. This latter may be made flat or may be a circular rod with the teeth cut entirely around it, as shown, and for many reasons the latter form is preferable. A chamber F is provided for this rack through the stock below the barrel and in a line with the centre of the revolving cylinder B. In order to operate the extractor by means of this rack, Smith places a toothed wheel G in the joint H in such a manner that it engages with the rack D above. The peculiarity of this pinion is that when the barrel is swung forward the pinion first revolves about one-eighth part of a turn, giving the cartridge shells room to clear the breech-block before they are started from the chambers of the revolving cylinder; the pinion is then caught and held by a pawl N at the lower side, the rack being consequently forced back or left behind, as shown in Fig. 2878, and with it the extractor, which as the barrel is turned farther forward on the hinge pushes out the shells, the head of the extractor catching under their flanges, as shown at T. A projection is formed on the stock in front of the pinion, and when the barrel is swung far enough for this projection I to strike against the head J of the pawl N and push it back, the pinion revolves freely and the rack flies forward to its former position, carrying with it the extractor, and also turning the pinion until it occupies its first place relative to the rack. In order to thus impel the rack forward when the pinion is released any suitably arranged spring may be used. In this instance Smith forms on the forward end of the rack a rod K, which has on its outer end a head and passes through a collar L made stationary by means of a set screw M in the chamber F at a point near the end of the rack when at rest. A spiral spring is coiled around this rod between its head and the collar, and when the rack is forced back towards the revolving cylinder the spring is compressed, its recoil restoring the rack when it is released. In this manner by merely throwing forward the barrel as far as it will go the shells are all extracted

and the extractor restored to its proper position for a new operation as soon as the barrel is returned to the breech.

In these fire-arms as heretofore constructed there has been no provision made for the pawl O, which in the ordinary construction projects beyond the face of the recoil-block in order to engage

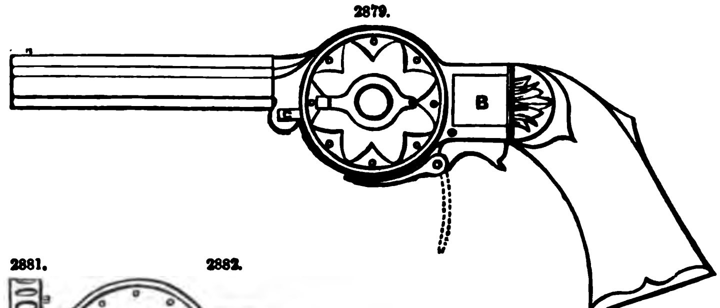
2878.



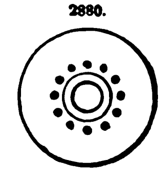
with the ratchet on the said cylinder, and is therefore always liable to be broken off by the projecting heads of shells or even by the ratchet itself when the pistol-barrel is forced suddenly back. In order to obviate this difficulty, Smith provides a half-cock notch on the tumbler, and arranges the pawl O in such a manner in relation to the same that when the hammer is at half cock the trigger presses against the lower end of the pawl at R, and the pivot-pin S being above this point the upper end or point of the pawl is consequently thrown back. The trigger must project slightly at this side of the tumbler to enable it to catch against the pawl. The pawl is thereby thrown out of line with the breech-block face and entirely out of the way, so that the barrel may be forced back with perfect safety when the piece is at half-cock.

Twelve-chamber Revolving Pistol.—Figs. 2879 to 2883 give in detail an arrangement for a twelve-chamber revolving pistol, the invention of M. T. Dromel. The idea of arranging many chambers in a circle is not new, but the manner in which the details have here been worked out is certainly original and deserving of merit. One of the chief objects aimed at in the introduction of this weapon has been to produce a light and portable revolving many-chambered pistol, whilst its small width and the absence of projecting points render it suited for carrying in the pocket, the sight at the end of the barrel being the only inconvenient part of the arrangement; but this might be dispensed with.

2879.

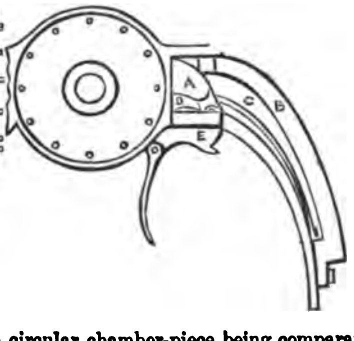


2880.

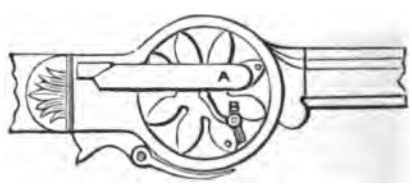


2881.

2882.



2883.

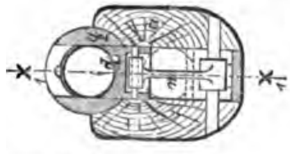


The circular chamber-piece being comparatively small, and easily shifted, a second chamber-piece ready loaded might with safety be carried in the pocket, and thus twenty-four charges might be

always available in cases of danger or emergency. Fig. 2879 shows the pistol complete. A is a catch closing the circular door, moving on a pivot at C, which holds the chamber-piece in its place; and B is a small slide, which draws out for the purpose of cleaning or repairing the lock. Figs. 2880, 2881, show the chamber-piece, Fig. 2882 shows the lock arrangement, and Fig. 2883, the opposite side of the pistol, with the hammer. In Fig. 2882, A is the principal part of the lock arrangement, which is attached by a joint to the trigger-block E. On pulling the trigger, the end of the trigger-block is elevated, and thus throws the piece A forward, which, pressing against a small projection on the hammer, raises it, draws out the point which enters one of the small holes, shown in Fig. 2880, whilst it at the same time presses against one of the small projections shown in Fig. 2882, and causes the chamber-piece to revolve. As soon as the next chamber comes opposite to the barrel, the hammer is released, and the spring B forces it powerfully back, when its point enters the next hole and explodes the cartridge, which contains its own cap; and as soon as the trigger is released the spring C draws back the piece A, whilst the smaller spring D gives its point a slight elevation, and thus raises it so that on the next discharge the point of A shoots out above the next point on the chamber-piece. In Fig. 2883, A is the hammer, from the end of which a small point projects, which enters holes shown in Fig. 2880, to explode the charge, whilst the small piece B is for the purpose of enabling the pistol to be carried safely in the pocket when loaded; for by raising the hammer and elevating B, so that the point on A passes through the hole in B, it is slightly raised away from the cartridge, and cannot, therefore, explode it.

The Magazine gun of Bethel Burton, illustrated by Figs. 2884, 2885, differs only from his other gun, Figs. 2844, 2845, by the addition of a magazine *a*, *r r*, *n*, underneath the barrel, from which the cartridges are supplied. The mechanism for conveying the cartridges from the magazine up and into the chamber of the breech consists of a crank-lever *m*, a spring m^1 which steadies the motion of the lever; a tray or carrier m^2, and a feed-regulating spring *n*. Fig. 2885 is a cross-section, at × ×, in which the tray or carrier m^2 and lever *m*, and the feed-spring *n* are situated. *r*, *r*, represent the cartridges in the magazine *a*, *r r*; a cartridge *r* is a so shown on the tray m^2, just taken from the magazine ready to enter the chamber when pushed forward by the motion of the bolt as the breech is closed. When the charge is fired and the bolt again withdrawn, the empty shell is thrown out and another cartridge carried up ready to enter the barrel. The arrangement for firing this arm differs somewhat from Burton's general arrangement before described: in this case he adopts a lever *k*, Fig. 2884, for the purpose of gaining power over a bent spring k^1 which has to be kept in place. The trigger k^2 acts on the end or point of a lever of the third order which moves round a pin in the centre and is made fast to a projection on the under-side of the breech. The action of the finger *j* is the same as in the other gun, Fig. 2845.

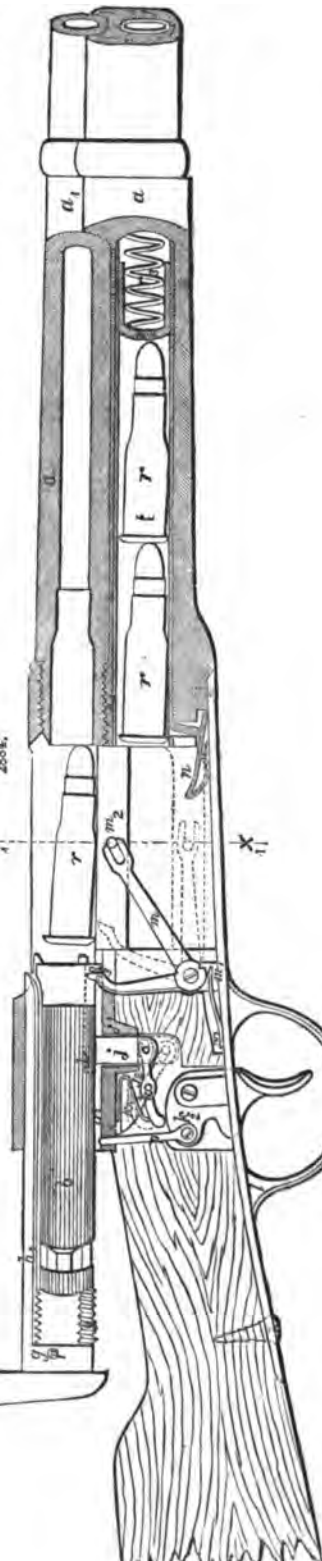
2885.



It is important to know that Burton's breech action, without being in any way altered, may, with his system of cartridge, be employed to work a magazine gun, and guns of different calibres.

Before speaking of cartridges we shall say something of the *fulminate of mercury*. This highly-explosive compound consists of protoxide of mercury united with an acid: *fulminic acid*, formed of cyanogen and oxygen, of which the formula is CyO or C_2NO; and is used for the manufacture of percussion caps. Fulminate of mercury

2884.



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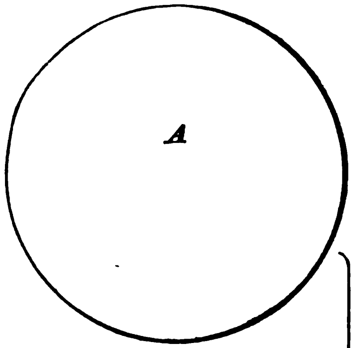

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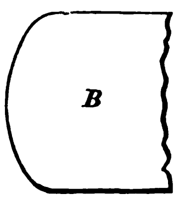
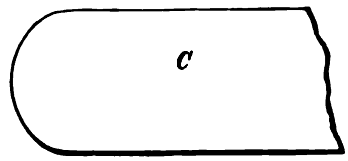


2889.



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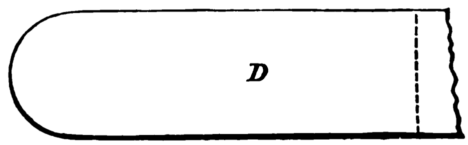

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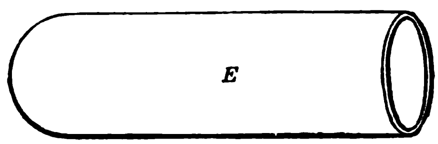
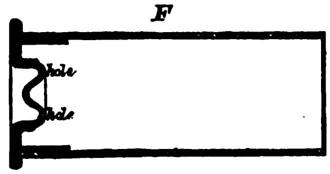


2892.

E_1

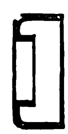
2893.

F



2894.

F_1



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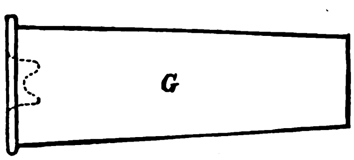

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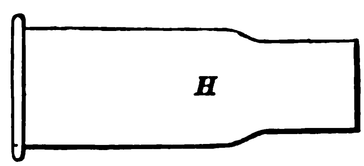

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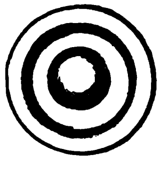

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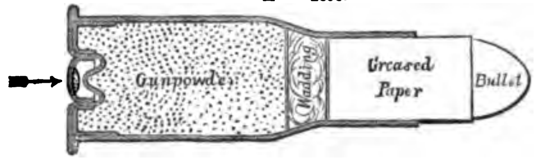

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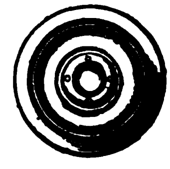
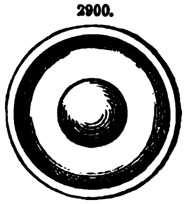


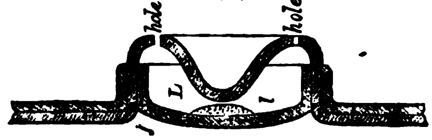
ENLARGED 4 TIMES

2900.

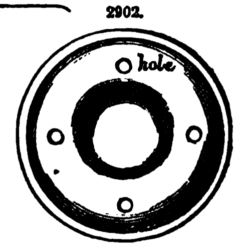


2901.

K



2902.



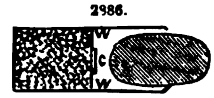
is prepared by causing alcohol to react on the acid proto-nitrate. A quantity of mercury is dissolved in 12 parts of nitric acid of 35° or 40° of Baumé, and 11 parts of alcohol at ·86 are gradually added to the solution; and while the temperature is slowly elevated, a lively reaction, accompanied by a copious evolution of reddish vapours, soon ensues, when the liquid, on cooling, deposits small crystals of a yellowish-white colour. Fulminate of mercury is one of the most explosive compounds known, and should be handled with great care, especially when it is dry, and it detonates when rubbed against a hard body. It dissolves readily in boiling water, but the greater portion of it is again deposited in crystals during cooling. The fulminating material of percussion caps is made of fulminate of mercury prepared as just stated, after having been washed in cold water. The substance is allowed to drain until it contains only about 20 per cent. of water, and is then mixed with ½ of its weight of nitre, which mixture is ground on a marble table with a muller of guaiacum-wood. A small quantity of the paste is then placed in each copper cap and allowed to dry, the fulminating powder in the cap being often covered with a thin coat of varnish to preserve it from moisture. We shall speak of this again when we treat of other explosive compounds. See GUNPOWDER.

Cartridges.—Most rifles have been invented to suit the cartridge, instead of the cartridge being devised to suit the rifle. A cartridge containing the means of its own ignition, is by no means a recent contrivance. The needle-gun cartridge has been in use for many years, and though not metallic it contains its own ignition. But the metallic cartridge for weapons of war was first largely adopted in the American armies during the rebellion, and was the parent of many inventions in breech-loading small arms, both in Europe and America.

The cartridge of the Prussian needle-gun is peculiarly its own: made for this gun, it can only be used in it or in a gun having a needle arrangement to reach the fulminate through the powder. It consists mainly of four parts, not enclosed in a metallic, but a paper cover. These parts are the powder, the fulminating cap, the carrier-wad, and the bullet. The latter is of an acorn shape, and weighs about an ounce, and the charge of powder is seventy-six grains.

Referring to Fig. 2886, the distinguishing features of this cartridge are the carrier-wad *w*, and the cap *c*. The carrier-wad is formed of strips of paper moulded into the proper shape by heavy pressure, and its uses are as follows:—It holds the cap *c* containing the fulminating compound, protecting it from chemical influence or other injury; it receives the first impulse of the explosion and transmits it to the bullet, thereby economizing the force of the powder: it is compressed into the grooves of the rifling, and thus imparts a rotary motion to the bullet, which does not itself touch the barrel, and hence the grooves never get clogged with lead; finally, it cleanses the barrel at every discharge of the gun, but the friction is very great. The wad accompanies the bullet through some 50 or 60 yds. of its flight, and about 20 yds. from the gun it strikes a target about 3 or 4 in. below the bullet-mark, and at this distance will pierce a pine board of over half an inch in thickness, so that, at short range, the gun may be said to carry two projectiles. This, however, may not always be an advantage, as in the case of firing over a line of troops at some distance in front, the wad might kill or wound a friend instead of a foe. The fulminate of the needle-gun cartridge was at one time believed to be kept a secret, but it is now generally known to consist of a mixture of chlorate of potash, antimony, and sulphur, in the proportions of five to three, to two of the respective chemicals. As already stated, the cartridge is enveloped in a paper case: this case is almost, if not entirely, consumed by the combustion of the powder, and to ensure its complete consumption a certain amount of air is provided for by the air-chamber or cavity surrounding the fore part of the needle-guide, hence there is no empty cartridge to take out of the gun before reloading. The ignition of the powder from the front is, however, the great feature in the needle-gun, as by this means it is all consumed and rendered effective.

2886.



The Needle-gun Cartridge

The process of making Bethel Burton's bottle-necked cartridge from solid brass or copper is illustrated by Figs. 2887 to 2902. A is a blank cut from a sheet of metal in a double-action press; while the blank is in the press a second punch draws it into the form B by forcing it through a die. B is then taken to a single-action press, in which it is again drawn and made to assume the forms C, D. The case is then cut to a length E by what is called a cutting-off machine. It is then put into another machine, termed a header, which forms the flange or base, as seen in Figs. 2892 to 2899; a cup is then formed in the head or base. The next process is to turn the bottom of this cup J in, to form an anvil on which the fulminate L *l* is placed and exploded. The holes marked in Fig. 2901, through which the fire passes to the powder, are then punched in another machine. A lining F′ is then placed on the inside base of the cartridge; this is intended to strengthen the base and to prevent the force of the explosion from rupturing the cartridge.

The cartridge case is then taken to a tapering press in which it receives the form G, Fig. 2895. The necking process is then performed, and the shape H, Fig. 2896, produced. K, Fig. 2901, is a section through the base, and I, Fig. 2898, a section through the cartridge, when complete. It must be observed that each process is performed after the case has been annealed.

FIRE-BOX. FR., *Boîte à feu*; GER., *Feuerkasten*; ITAL., *Focolare Camera del fuoco*; SPAN., *Caja de fuego*.

See BOILER.

FIRE-BRIDGE. FR., *Pont de chauffe*; GER., *Feuerbrücke*; SPAN., *Directriz de fuegos*.

See BOILER. CHIMNEY. LOCOMOTIVE ENGINE. MARINE ENGINE.

FIRE-CLAY. FR., *Argile refractaire*; GER., *Feuerfester Thon*; ITAL., *Argilla apira*; SPAN., *Tierra refractaria*.

Fire-clay is a kind of clay chiefly pure silicate of alumina, capable of sustaining intense heat, and hence used in making fire-bricks.

Composition of Clay.

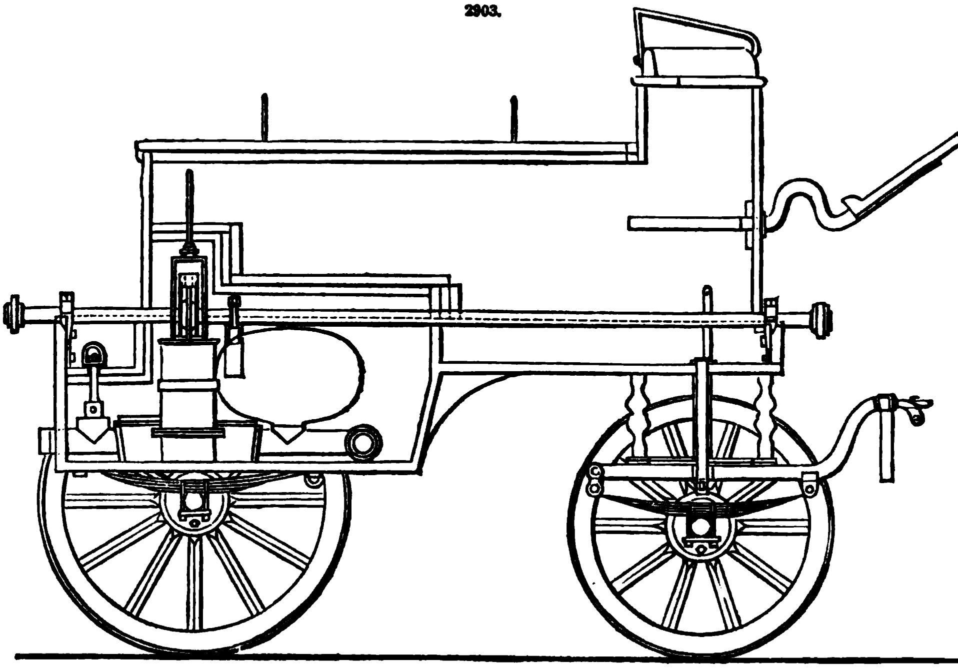
	Chinese Kaolin.	Stourbridge Fire-clay.	Pipe-clay.		Chinese Kaolin.	Stourbridge Fire-clay.	Pipe-clay.
Silica	50·5	64·1	53·7	Magnesia ..	0·8	0·9	..
Alumina ..	33·7	23·1	32·0	Potash, soda ..	1·9	..	..
Water	11·2	10·0	12·1				
Oxide of iron	1·8	1·8	1·4		99·9	99·9	99·6
Lime	..	..	0·4				

See Founding and Casting. Porcelain. Terra Cotta.

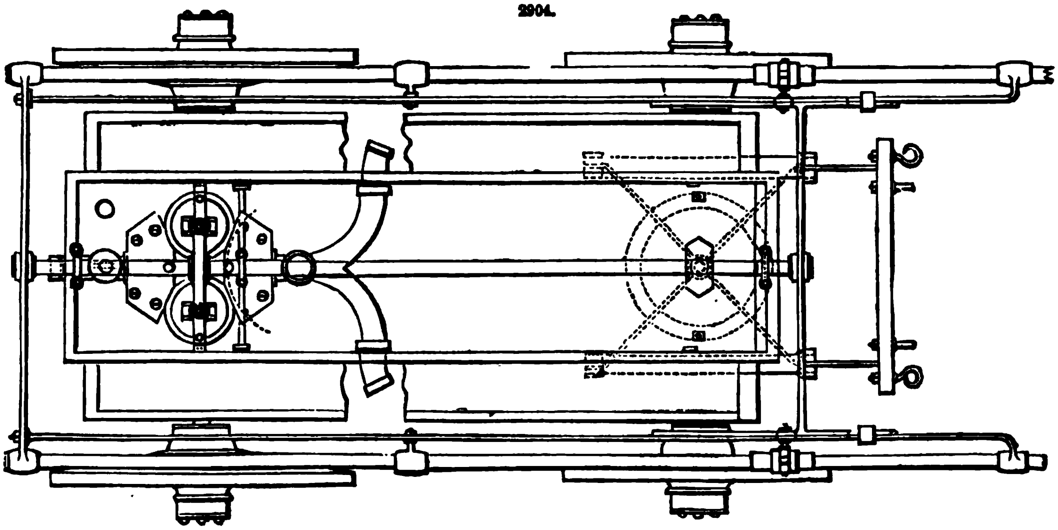
FIRE-ENGINE. Fr., *Pompe à incendie;* Ger., *Feuerspritze;* Ital., *Tromba da incendio;* Span., *Bomba de incendios.*

Merryweather and Sons' Hand-power Fire-engine, Figs. 2903, 2904.—This engine is fitted with gun-

2903.



2904.



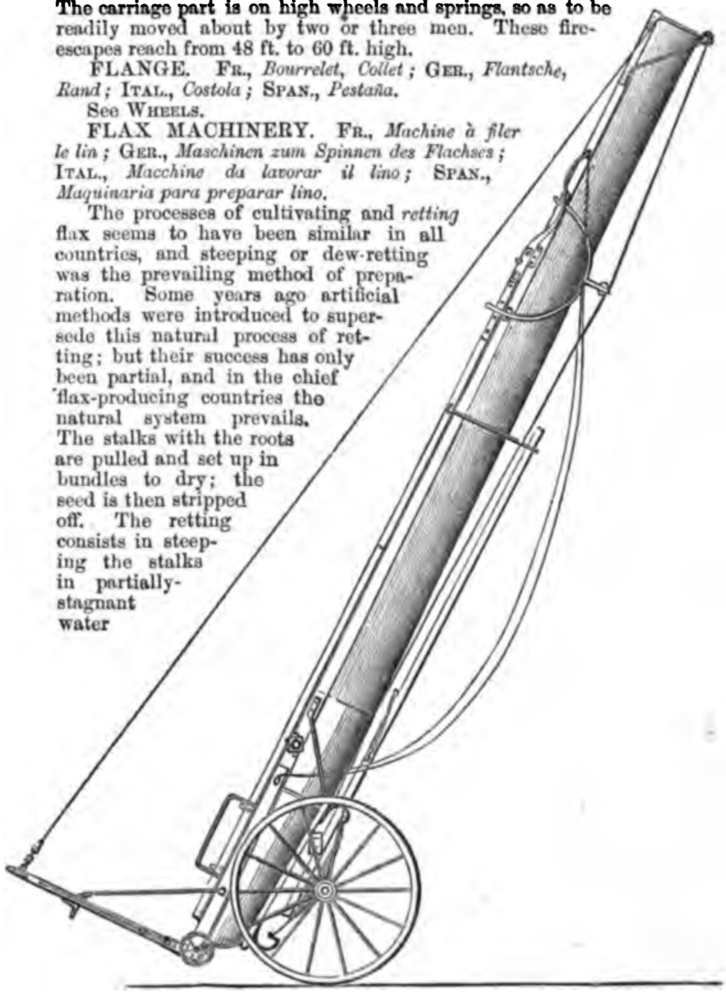
metal or brass valves to the pumps, in such a manner that they are not injured by pumping foul and gritty water, or affected by hot or cold climates. The valves are easy of access. It is fitted with

suction-pieces, to which flexible suction-hoses are attached, and is provided with a stop-valve so that water can be pumped out of its own cistern when required. The larger engines have two outlets, so that two streams may be thrown at once; the delivery-piece has an air-vessel attached to it. The works are fitted in hard wood, and occasionally in metal, cisterns, and are worked by a shaft and cross-levers, to which are attached the working levers for the men, these being arranged so as to fold up when travelling, and to extend out when the men are at work. Above the works is a strong box, which contains the hose and apparatus, and on which the firemen ride. At each side of the cistern is a pocket to contain the suction-hoses. The engine is mounted on high wheels and springs, and is fitted with a fore-locking carriage, which is provided with a pole for horses and drag-handle for men.

FIRE-ESCAPE. FR., *Appareil de sauvetage*; GER., *Rettungsapparat*.

The Fire-escape was invented by a very talented artist named Wyvall. Merryweather and Sons' fire-escape, Figs. 2905, 2906, has a strong main-ladder with a sail-cloth trough at the back for sliding down in safety, and this trough is protected either by copper gauze or netting; it has a turnover ladder simply worked by levers and ropes, and an extra piece to attach so as to reach higher windows. All the ladders are kept as light as possible for easy transit, and are bound back and front with wire-rope sunk in so as to gain strength. The carriage part is on high wheels and springs, so as to be readily moved about by two or three men. These fire-escapes reach from 48 ft. to 60 ft. high.

2905.



2906.

FLANGE. FR., *Bourrelet, Collet*; GER., *Flantsche, Rand*; ITAL., *Costola*; SPAN., *Pestaña*.

See WHEELS.

FLAX MACHINERY. FR., *Machine à filer le lin*; GER., *Maschinen zum Spinnen des Flachses*; ITAL., *Macchine da lavorar il lino*; SPAN., *Maquinaria para preparar lino*.

The processes of cultivating and *retting* flax seems to have been similar in all countries, and steeping or dew-retting was the prevailing method of preparation. Some years ago artificial methods were introduced to supersede this natural process of retting; but their success has only been partial, and in the chief flax-producing countries the natural system prevails. The stalks with the roots are pulled and set up in bundles to dry; the seed is then stripped off. The retting consists in steeping the stalks in partially-stagnant water for about three weeks, during which time a fermentation takes place. The flax fibre being the bark or rind of the flax plant, of which the interior or core is a semi-wooden substance called boom, the object of retting is partially to decompose this woody substance, so that it becomes brittle when dry; and the fermentation should not be continued so long as to injure the strength of the fibre, but long enough to loosen the gum which causes the bark to adhere to the woody portion. The process therefore requires great care and experience, for either too much or too little retting is detrimental to the fibre. When thoroughly dried, the flax is ready to be broken, which is done by passing it in small bunches through pairs of fluted rollers; these break the woody core into short lengths, and also partially split the bark.

The next operation is called *scutching*, which in most flax-producing countries is still done by hand in preference to mill-scutching. In hand-scutching, a bundle of the broken flax is suspended alternately at each end and struck with a wooden beater, by which the broken pieces of the core or boom are dusted out from between the fibres. This operation requires considerable dexterity.

The next process is to *heckle* the flax, which was formerly done by hand by the flax-dressers. The heckle is a board set closely with pins about 4 in. long, which are ground to a fine tapering point; this board is fixed with the points of the pins upwards, and the bundles of flax are drawn over the pins until the flax is sufficiently split. Other heckles of varying degrees of fineness are also used, partly to bring up the fibres to the requisite degree of fineness, but chiefly to clear out the short loose fibres or tow which were split off in the first heckling. The dressed flax was sold in this state under the name of lint, for spinning by hand, which was formerly a common domestic occupation both of rich and poor.

In the early application of machinery to preparing and spinning flax, the fibres were drawn between two pairs of rollers, the first called the receiving rollers and the other pair the drawing rollers, the two pairs of rollers being placed at varying distances apart, according to the length of fibre to be operated upon. The drawing rollers ran at from five to ten times the surface speed of the receiving rollers, so as to elongate the *sliver* or bundle of fibres. Subsequently a series of travelling gills was introduced between the receiving and drawing rollers, these being a succession of small transverse combs, called gills, travelling continuously forwards in the longitudinal direction of the fibres about 5 per cent. faster than the surface speed of the receiving rollers. This proved a step in the right direction, and was followed by the introduction of spinning frames similar to those employed in spinning cotton, but with the modifications rendered necessary by the difference in the material to be spun; the chief feature in the flax machinery being the great difference in the distance between the receiving and the drawing rollers, which amounts to as much as 20 to 24 in. distance in the case of flax, instead of at most only a few inches in the case of drawing cotton, on account of the great difference between the length of fibre in the two materials.

The flax was at first kept quite dry in the spinning process; but a mode of damping the yarn by means of a piece of wet cloth held in contact with the drawing roller was afterwards employed, which had the effect of laying the loose ends of the fibres in the same manner as is done by wetting the fingers in hand-spinning. But the great expansion that has taken place in the flax trade is due to the principle of wet spinning introduced by Mr. Kay; the flax rovings being first put into warm water and allowed to stand until fermentation took place, by which the flax was macerated and brought into a state bordering on putrefaction. This was found to be a dangerous process, for if continued too long the strength of the fibre was destroyed. Subsequent experience showed that it was only necessary to pass the rovings through hot water in order to attain a better result, and that no maceration was requisite. It is only the natural gum contained in the flax fibres that requires to be dissolved or softened, in order to allow them to be drawn asunder; and the slimy nature of the rovings when wet allows this to be done to almost any extent. When spun dry by machinery, No. 40 yarn was about the maximum degree of fineness attained, in which the bundle of 60,000 yds. length weighs 5 lbs., and this size of yarn is suitable for ordinary linen cloth; but now by the improved process of wet spinning, Nos. 300 to 400 are ordinarily attained, in which sizes of yarn the bundle of 60,000 yds. length weighs only $\frac{2}{3}$ and $\frac{1}{2}$ lb. respectively. The bundle of flax yarn consists of 200 leas or hanks of 300 yds. each, making altogether 60,000 yds. length; and the Nos. are marks indicating the sizes of the yarn in inverse proportion to the weight of the bundle, as in the following Table, the unit being No. 200 weighing 1 lb.:—

No. 10 yarn	weighs 20 lbs. a bundle.	No. 200 yarn	weighs 1 lb. a bundle.
No. 20 "	10 lbs. "	No. 300 "	$\frac{2}{3}$ lb. "
No. 40 "	5 lbs. "	No. 400 "	$\frac{2}{4}$ or $\frac{1}{2}$ lb. "
No. 50 "	4 lbs. "	No. 500 "	$\frac{2}{5}$ lb. "
No. 100 "	2 lbs. "	No. 1000 "	$\frac{2}{10}$ or $\frac{1}{5}$ lb. "
No. 200 "	1 lb. "	No. 1200 "	$\frac{2}{12}$ or $\frac{1}{6}$ lb. "

The whole of this advantage indeed is not due to the principle of wetting the roving, but many improvements in the preparation have contributed to the attainment of this result. One of the conditions of spinning flax wet is to bring the receiving and drawing rollers within a few inches of each other, and thus reduce the length operated upon of the fibre of the flax to the distance between the bite of the receiving and drawing rollers. Yet notwithstanding all the improvements of machinery, hand-spinning still produces a yarn of three times the fineness hitherto attained by the finest machine; for while Nos. 300 to 400 are the finest produced by the machines, the hand-spinner produces yarn from Nos. 1000 to 1200, in which the bundle of 60,000 yds. length weighs only $\frac{1}{5}$ and $\frac{1}{6}$ lb. respectively. This finest kind of yarn, the value of which is equal to that of gold, weight for weight, is produced chiefly in Belgium, and is used for making Brussels lace. The subsequent manufacture of flax after the yarn is produced presents great variety, the fabrics made from it ranging from the roughest Dudley cambric used for nail bags to the finest lawn, and from the stoutest ship's sail to the lightest gossamer lace.

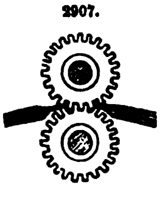
Since the introduction of the principle of spinning flax wet, various methods have been adopted to render the fibre of the flax finer, or in other words to split it up into a greater number of fibres by the process of heckling. In order to obtain the finest fibre, it was found necessary to break or cut the flax into three lengths: the top of the plant, the middle, and the root end. Of these the middle is the best part, owing to the fibres being there most uniform in thickness. By this plan of dividing the natural length of the flax into three lengths, which is designated the cut-line system, a very much smaller proportion of short fibres is produced in the heckling process than by heckling the fibre the full length of the plant; and consequently the fibres can be split much finer, and a larger proportion of yarn can be produced from a given quantity of flax, the degree of fineness being

taken into account. Another system is to cut the length of fibre in half; but this although partially pursued is wrong in principle, as the flax is then cut in the middle or most valuable part of the fibre, and each length has one bad end, the tapering end of the top of the plant, and the coarse end of the root. A third system is to heckle the flax the whole length of the fibre, which is called the long-line system, and is the most economical for the ordinary numbers of yarn that always constitute the great bulk of the manufacture. On this system a greater weight of flax can be passed through the heckling and preparing machinery in a given time: and a longer draft can be used at the spinning frame, that is the excess of surface speed of the drawing rollers above that of the receiving rollers can be made much greater than in the three-cut and two-cut systems, thereby producing a greater drawing action and making a finer thread, whilst reducing also the labour in attending to the process. The machinery used in the three-cut and two-cut systems is the same as in the long-line process, only that in the former it is finer in the gills and rollers and shorter in the reach or distance between the pairs of rollers. For some descriptions of manufacture it is absolutely necessary to use the long-line process, as, for instance, in making the best kind of sail-cloth, which is used in the royal navy and in the finest long-voyage vessels. For this purpose the longest and strongest flax is selected, and prepared with the greatest care in the processes of heckling, drawing, and roving, so as to preserve the fibres as long as possible; and in the spinning, which is done dry, very short drafts are used, that is, the excess of surface speed of the drawing rollers above that of the receiving rollers is comparatively small, so as not to break the fibre any more than can be avoided. The government authorities insist upon a test of both weight and strength at the same time, in order to get the sails both strong enough to resist the wind and also as light as possible for the sailors to handle; for as the weight of the mainsail of a first-class ship amounts to more than a ton, it is no easy task to handle it in a gale of wind and rain.

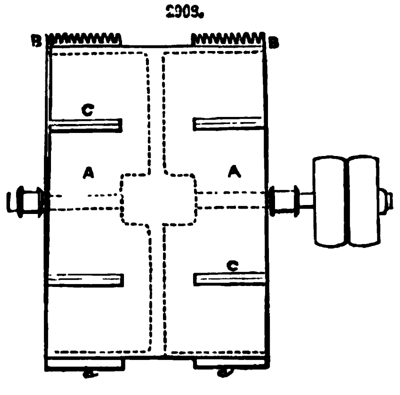
The machinery at present in use for preparing the flax and spinning it into yarn for weaving is shown in Figs. 2907 to 2925.

Fig. 2907 represents the breaking rollers, which are fluted iron rollers coupled together by spur-wheels: and both top and bottom rollers are supported in journals, so as to prevent the flutes from touching each other. The spaces between the teeth of the flutes are also much wider than the teeth working into them, so that, as the rollers revolve, the flutes never come in contact; otherwise the iron would damage the fibre. The object of passing the flax between these rollers is simply to break the boom or woody interior of the flax.

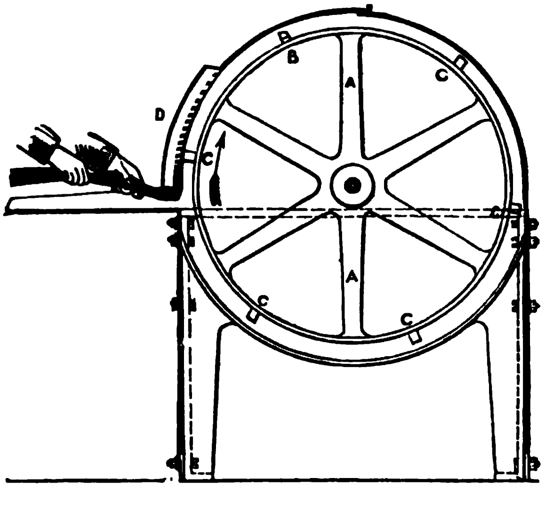
2907.



2908.



2909.

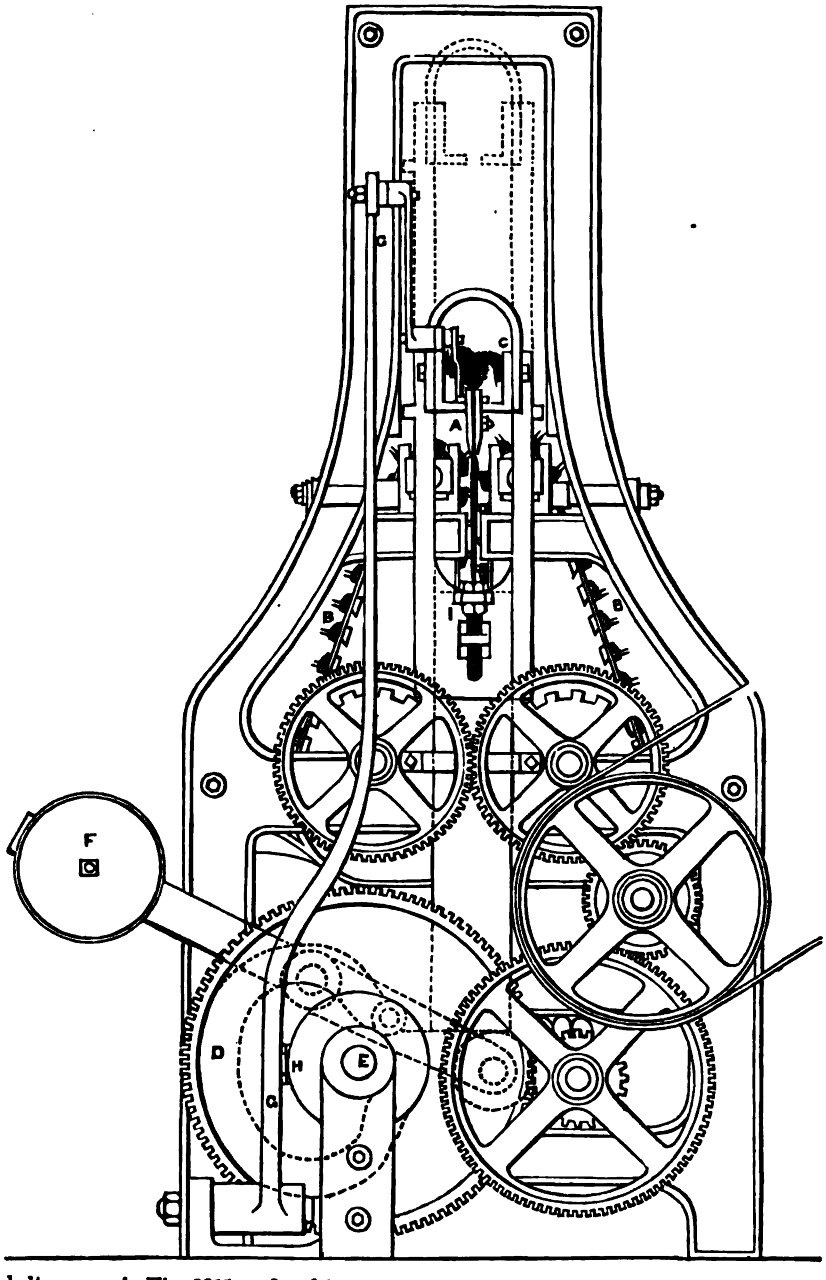


After the flax has been broken between the rollers, it is taken to the scutching machine, shown in Figs. 2908, 2909. The scutching cylinder A rotates in the direction of the arrow at about 300 revolutions a minute or 2800 ft. a minute speed of circumference, and dashes out the broken boom against the grating D by means of the toothed and plain projections B and C. The drawing shows one pair of combs B and five pairs of plain square beaters C C C upon the cylinder A, which are found to act well; but the number of either may be altered. The strick of broken flax is fed into the machine by the attendant up to half its length; and when the boom is thoroughly beaten out, it is drawn back and the other half inserted in the same way. The broken boom beaten out through the grating D escapes by an opening at each end of the grating. The ends of the casing of the machine being closed, a considerable current of air is drawn in through the grating D by the rapid rotation of the scutching cylinder, which is an essential feature in this operation, in carrying away the refuse and dust, and producing a gentle pressure of the flax against the projecting beaters upon

the cylinder. The bottom of the casing of the scutching machine is open, and communicates with a flue or culvert, through which the refuse and dust are carried away by the current of air.

The next process is to heckle the flax, and Fig. 2910 shows an end elevation of the Heckling Machine. The flax is divided into small stricks, and each is held between a pair of clamps A called holders, made sometimes of hard wood, but latterly of steel. These are closed firmly together

2910.

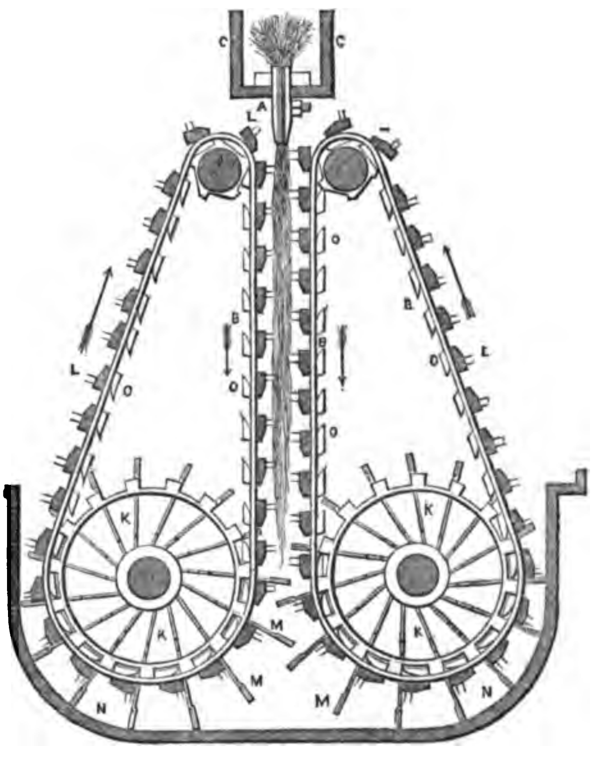


by a bolt, as seen in Fig. 2911, and are lined with either felt or india-rubber to form a cushion for the fibre to bed upon. The heckling machines vary in length, having sometimes four, six, or eight holders in a row; and the heckles B B have corresponding degrees of fineness, according to the amount of heckling that the flax will bear, the stricks of flax being submitted first to the action of the coarsest heckles, and then to the finer heckles in succession. The holders A are carried in a trough C, which extends the entire length of the machine, and also projects some distance at each

end, so as to afford room for feeding in at one end the newly-charged holders and removing from the other end those containing the heckled flax. The trough C receives a vertical motion from two cams D, shown by the dotted lines, mounted on the shaft E below, the weight of the trough being balanced by the weighted lever F. The form of the cams D is so arranged as to bring the pendent end of the flax gradually under the operation of the heckles, and also to allow a slight pause when the trough has descended to its lowest point, as shown in Figs. 2910, 2911, so that the heckles may comb out the fibres straight, and effectually clear out the tow. The trough C then rises gradually; and when it has reached its highest position, as shown dotted in Fig. 2910, the row of holders A are pushed forwards along it, by a series of pawls mounted upon a bar extending the entire length of the trough, and acted upon by the lever G and cam H. Each strick of flax is thus carried along to the next gradation of heckles, and the trough C then again descends as before. The set screw I, Fig. 2910, is for the purpose of adjusting the height of the trough A, so as to allow the holders to come down as near as possible to the bite of the heckles.

Fig. 2911 is a transverse section through the middle of the heckling machine. The sheets of heckles B B are made of leather straps passing round the small pulleys J J at top, and round the larger driving pulleys K K below, travelling at the rate of about 800 ft. a minute in the direction indicated by the arrows. The heckle-bars L L are of wood, attached by only one edge to the straps B, so that when they have passed over the top pulleys J J the heckle-pins may strike into the pendent flax as nearly at right angles as possible, as seen at the top of Fig. 2911. The heckles then descend in a vertical line until they reach the lower pulleys K K. These pulleys are grooved radially, and small slides carrying small iron rods M M are thrown out by the centrifugal force just below the centre of the pulleys. The rods M are for the purpose of stripping off any tow or short fibres of flax which may have remained between the heckle-pins after they have passed through the flax: and as the pulleys K revolve, the rods M are pushed back into their former position by sliding against the guides N, until they reach the upper side of the pulleys, when their weight overcomes the centrifugal force; and they remain drawn back until again thrown out below the centre to strip the tow off the heckle-pins. There are also a series of iron teeth O O attached to the inside of the leather straps B, which act as drivers to the straps, and keep the heckle-bars L always in proper horizontal position, by ensuring both the straps B being driven always at the same rate and without any chance of slipping; these teeth are driven by the teeth of the driving pulleys K K, and the small pulleys J J at top are also notched to receive them, the inner faces of the teeth O being rounded off to the proper curve for forming part of the circle of the upper pulleys J J in passing over them.

2911.



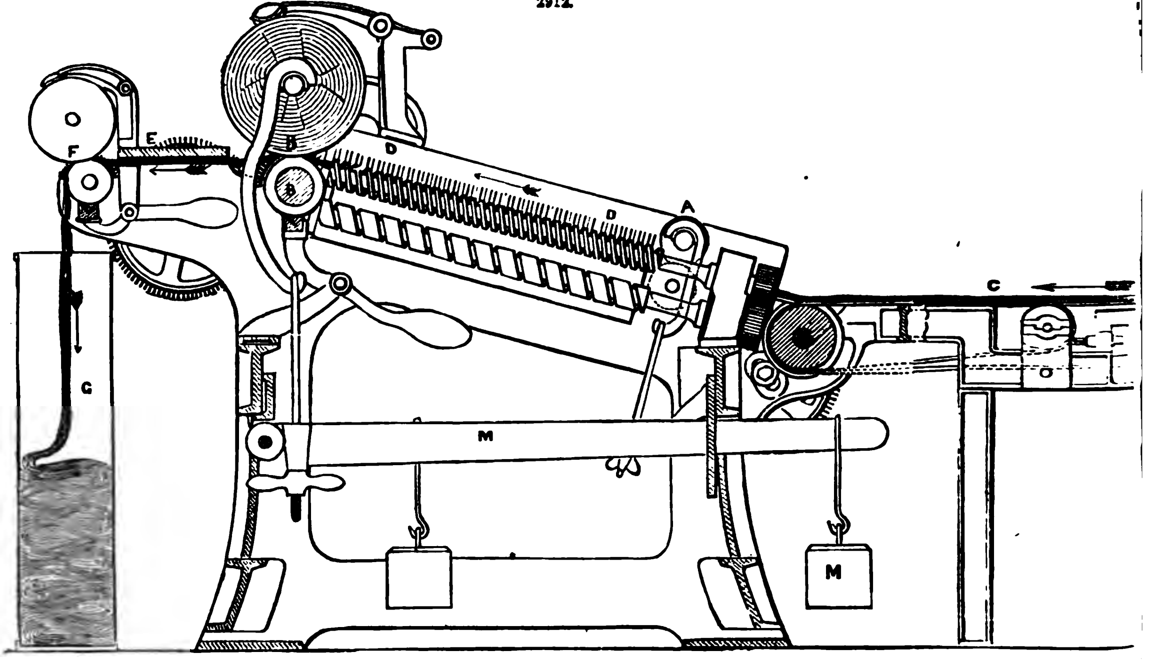
The main difficulty to be encountered in the heckling process has always been to obviate the large amount of waste that is made in the operation; and though heckling machines have been constructed in great variety, the same drawback of excessive waste has attended each, the proportion of the dressed line, or finished flax after the heckling, being as small as only 40 per cent. of the flax put into the machine in the lower qualities of flax, but ranging in the better qualities from 60 to 75 per cent. Heckling machines are also sometimes made with double sets of heckles and holders, for the sake of economy of construction and working; and this may be an advantage in heckling the best kinds of flax. The lower qualities, such as Egyptian and some kinds of Baltic flax, require the least amount of heckling; whilst the best kinds of Flemish and Irish flax, which are strong in the fibre, are capable of being heckled to almost any degree of fineness.

In the next operation the dressed line or heckled flax, which has been obtained thus far in the form of a number of separate stricks of irregular thickness and quantity, is spread and drawn into a continuous sliver like a ribbon, by the combined action of a series of combs and drawing rollers.

Fig. 2912 is a longitudinal section of the Long-line Spreading Frame, so called because the distance between the receiving rollers A and the drawing rollers B is made long enough to take in the greatest length of fibre that has to be worked on the long-line system. The stricks of heckled flax

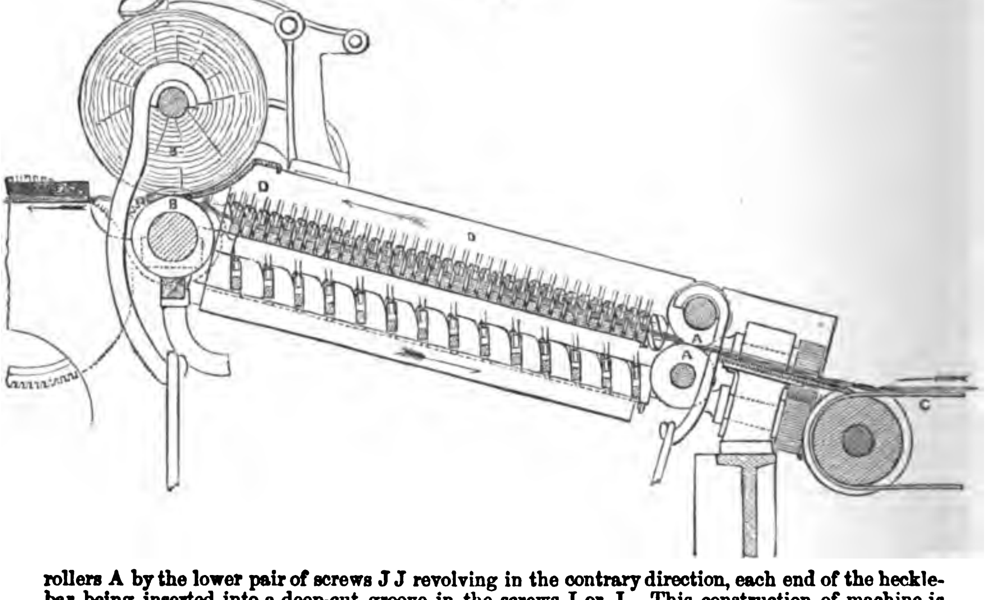
are laid down upon the endless travelling feed-sheet C, which carries the flax forwards to the receiving rollers A; and between these it passes on to the inclined bed of heckles or gills D, and then between the drawing rollers B, through the doubling plate E, and between the delivery rollers F, which deliver the continuous sliver into the can G, ready to be removed to the next process, the course of the flax through the machine being indicated by the arrows.

2912.



The heckle-bars or gills D are supported at each end upon the slides H, as shown enlarged in Figs. 2913 and 2915; and they are traversed forwards towards the drawing rollers B by means of the upper pair of screws I I revolving in one direction, and back again towards the receiving

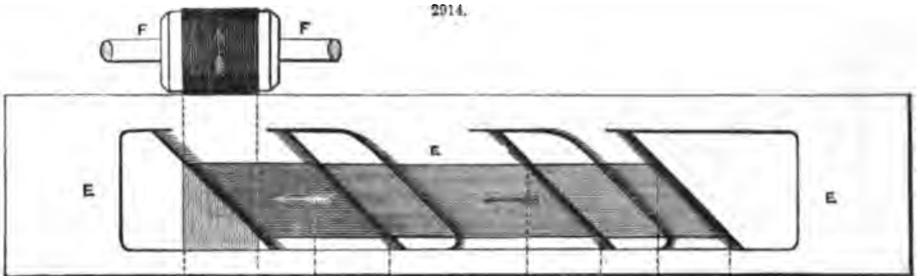
2913.

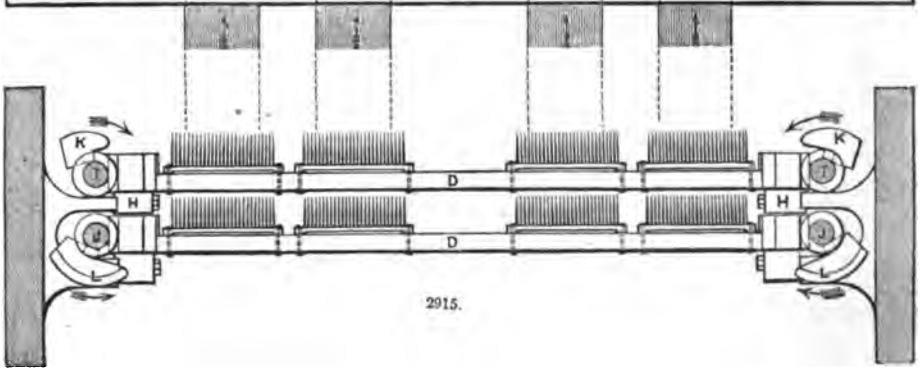


rollers A by the lower pair of screws J J revolving in the contrary direction, each end of the heckle-bar being inserted into a deep-cut groove in the screws I or J. This construction of machine is accordingly known as the screw-gill arrangement; and previous to its invention chains and other methods of propelling the heckle-bars were employed. The heckle-bars are carried forwards by the

upper screws I I till they arrive close to the lower drawing roller B, Fig. 2913, when each bar in succession drops down at the end of the slides H into the groove of the lower screws J J; these are made with a much longer pitch of groove than the upper screws I, partly to economize the number of heckle-bars, and partly to ensure the bar which has just dropped into the lower screw being carried back sufficiently out of the way, to allow the succeeding bar ample room to drop in the same manner. A cam K, Fig. 2915, is placed at the termination of the groove in the upper screw I, so that if the heckle-bar should happen not to drop by its own weight into the lower screw, the cam K will force it down, as shown in Fig. 2916. The heckle-bars are then carried back by the lower screw towards the receiving rollers A; and on each bar arriving close to the lower receiving roller, a

2914.

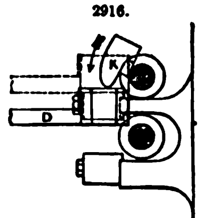




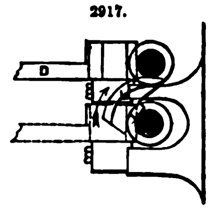
2915.

cam L, Fig. 2915, at the end of the lower screw raises the bar into the groove of the upper screw, as shown in Fig. 2917, when the heckle-pins penetrate the flax, and the heckle-bar begins to travel forwards again towards the drawing rollers. The lifting cams L are continued through about one-third of the whole circle, so as to support the heckle-bar on a level with the slide H, until the screw I carries it a short distance along the slide, and thus to prevent it from dropping down again into the lower screw, which was a serious defect in the earlier screw-gills.

2916.



2917.



The screw-gills employed in the further process of preparing the flax for spinning are precisely the same in principle as those now described, only varying in their degrees of fineness. The system of screw-gill machinery shown in the drawings is called the long-line system, because by it the flax is worked the natural length of the fibre; and the machinery used for the cut-line and tow is just the same in principle, only shorter and finer to suit the length and fineness of the flax or tow operated upon.

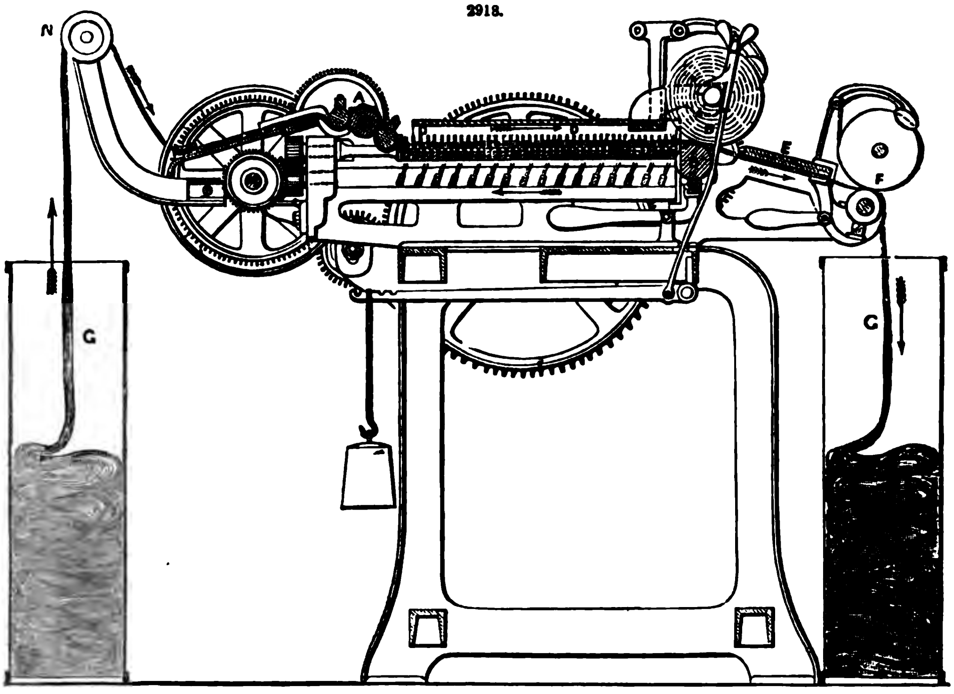
The receiving rollers A, Fig. 2913, travel at a surface speed of about 5 ft. a minute, and the heckle-bars about 5 per cent. faster, so as to hold the flax in a slight tension. The surface speed of the drawing rollers B is from fifteen to thirty times greater than the speed of the heckles, or from 70 to 140 ft. a minute; consequently the fibres are combed or drawn between the pins, and the length of sliver delivered into the can G is elongated to about fifteen to thirty times the length taken in by the receiving rollers A. One object of this operation is to lay the fibres parallel to one another, and also to prevent the long fibres from carrying the short fibres along with them, and thus making an uneven sliver, which must produce uneven yarn. The upper of the drawing rollers B is made of wood, and is heavily pressed down by the links, levers, and weights M.

The flax is delivered from the drawing rollers B in a continuous sliver of ribbon-like form, from 4 to 5 in. wide, and four of such slivers are drawn by the machine, as shown in Figs. 2914, 2915: these are then passed through the doubling plate E, and all four are rolled together into a single sliver of the same width by passing through the single pair of delivery rollers F. The doubling plate E, shown in plan in Fig. 2914, has openings opposite each pair of drawing rollers at an angle of 45°, through which the slivers are passed, whereby they are made to travel first at right angles

to the line of delivery from the drawing rollers, and are afterwards turned again into the same direction towards the delivery rollers F, which deliver the final single sliver into the can G, Fig. 2912.

The next operation is to re-draw and double again the sliver delivered from the long-line spreading frame; and Fig. 2918 shows the second Long-line Drawing Frame. A number of cans G, generally eight, containing the slivers delivered from the spreading frame, are placed behind this drawing frame, whence the sliver passes over a high conductor N, in order to allow a considerable length to hang pendent, and thus straighten out the creases made by pressing it down in the can G. The sliver then passes to the receiving rollers A, which are three in number, the object being

2918.



to hold the sliver firmly, and not allow the gills or heckles D to draw it beyond the surface speed of the rollers, which is about 6 ft. a minute. The further operation of this machine is precisely the same as that of the spreading frame, the eight slivers being combed and drawn by the gills D and drawing rollers B, and then doubled by passing through the doubling plate E, and rolled into a single sliver by the delivery rollers F. The gills D, however, are finer and the rollers smaller than in the spreading frame. The speed of the gills is about 6½ ft. a minute, and the surface speed of the drawing rollers B and delivery rollers F about 130 ft. a minute; and the length of the sliver delivered by the rollers F is consequently elongated to about twenty times the length taken in by the receiving rollers A.

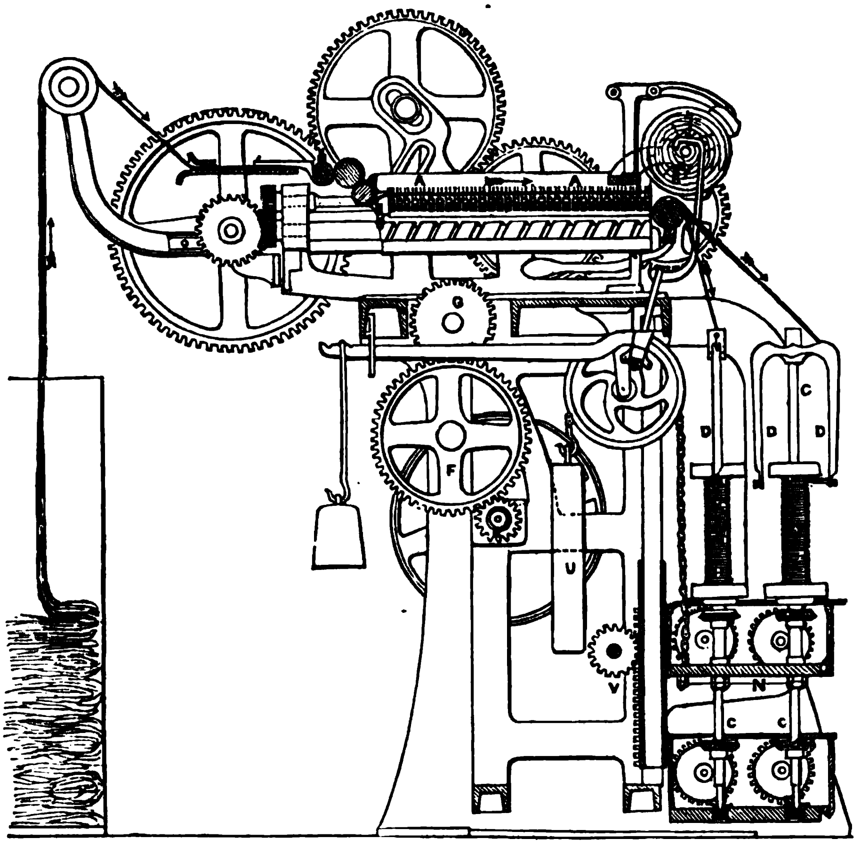
The slivers from this machine are then taken to a third drawing frame, of precisely the same construction, but with still finer gills and smaller rollers; by this means the sliver is further elongated about fifteen times, the object being to reduce it in width and thickness. From this third drawing frame the slivers are then taken to the roving frame.

Figs. 2919 to 2922 represent what is known as the Screw-gill Regulating Roving Frame, in which the delicate sliver of flax that has been produced by the previous processes is still further combed and drawn by gills and drawing rollers, and is then twisted into a roving and wound upon a bobbin.

This machine as a whole is perhaps the most complicated one used in spinning any kind of material, and has taken many years to bring it to the present state of perfection. The lower or regulating portion of the frame, by which the speed of winding the roving upon the bobbin is regulated according to the gradually increasing diameter of the bobbin, is similar to that used in the cotton manufacture, where this system of machine was first introduced; but when so much of the machine as is used in the cotton manufacture is added to the screw-gill machinery, the two make what may be considered the most ingenious and perfect machine used in textile manufacture, and great ingenuity has been applied to overcome the numerous obstacles met with in perfecting this machine. The screw-gill part A, Figs. 2919, 2920, is precisely the same as in the drawing frame last mentioned, only so much finer; for here the sliver is reduced to the smallest size previous to receiving the twist which changes it into a roving. The speed of the gills is about 6 ft. a minute, and the surface speed of the drawing rollers B about 90 ft. a minute, whereby the sliver is finally elongated about fifteen times.

The special part of the roving frame, independent of the screw-gills and drawing rollers, is the regulating portion, situated in the lower part of the machine, which takes up the sliver as delivered by the drawing rollers, and after putting in the twist winds it upon a bobbin with a uniform but slight tension, not sufficient to elongate the delicate roving: and as each successive coil presents a larger diameter than the preceding, the speed of the bobbin has to be regulated or gradually increased for winding the roving, which is delivered at a uniform rate from the drawing rollers.

2919.

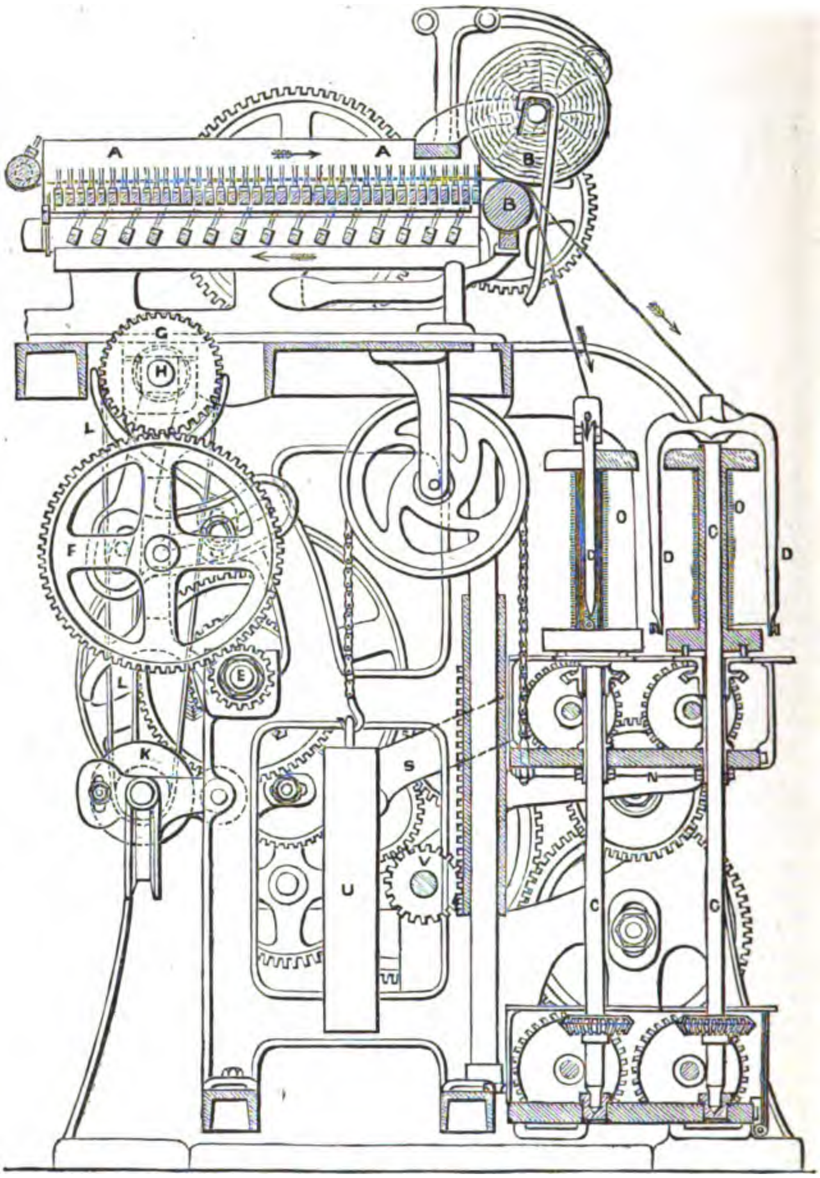


The bobbin-spindles C C, Figs. 2919, 2920, carrying the fliers D D, are driven at a uniform speed from the driving pulley upon the end of the main longitudinal driving shaft E, through a train of spur-wheels driving the skew-bevel wheels at the bottom of the spindles C. The screw-gills A and drawing rollers B are also driven at a uniform speed by means of a change pinion on the end of the driving shaft E, through the intermediate wheel F working into the wheel G on the end of the top cone shaft H. The lower cone K, Figs. 2921, 2922, receives its motion from the upper cone H through a strap L, which is made to travel longitudinally along the cones by means of a chain M passing over a pulley, with a weight hung at the end sufficient to draw the strap-guide along two slide-rods that extend the length of the cones, or about $2\frac{1}{4}$ ft. The speed of the lower cone is thus varied according to the diameters of the cones at the point where the strap may be working. The advance of the strap-guide is governed by an escapement motion acted upon at each vertical reciprocation of the bobbin-lifter N. The bobbins O O run loose upon the bobbin-spindles C, and are themselves driven in the same direction as the spindles C, through the intervention of the regulating gearing and the skew-bevel wheels carried by the bobbin-lifter N.

Upon the driving shaft E is keyed a mitre-wheel I, Fig. 2922, which drives two mitre-wheels mounted in the disc of the spur-wheel P; and these again drive another mitre-wheel J running loose upon the driving shaft E. A spur-wheel R upon the boss of the last mitre-wheel J drives the train of spur-wheels indicated by the dotted lines in Fig. 2921; these are mounted on the jointed rocking frame S, Fig. 2920, and communicate motion to the longitudinal shafts in the bobbin-lifter N, which carry the skew-bevel wheels that gear into the bobbin-pinions. The bobbins O O are thus caused to revolve in the same direction as their spindles C, but at a somewhat slower speed. If the disc-wheel P were not allowed to rotate at all, the bobbins O would be driven, like their spindles, at one uniform speed; and if the disc-wheel P were driven at the same speed as the driving shaft E, no motion whatever would be communicated to the train of wheels which drives the bobbins O; therefore by regulating the motion of this wheel P any required speed can be com-

municated to the bobbins. A pinion on the shaft of the lower cone K gears into a train of spur-wheels and pinions, so as considerably to reduce the speed at the pinion T, which gears into the disc-wheel P, thereby governing this wheel in accordance with the speed imparted to the lower cone. The rotation of the mitre-wheel I, keyed upon the driving shaft, has a tendency to drive the disc-wheel P at a considerable speed, so that the lower cone K is required to retard instead of actually driving it. (See Fig. 2189.)

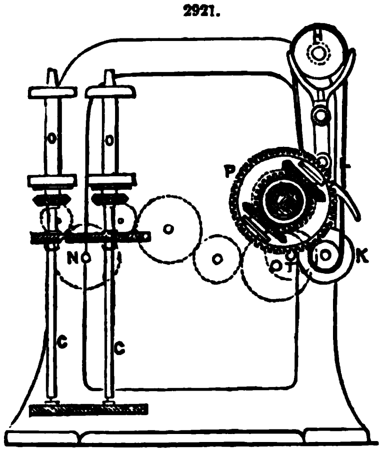
2920.



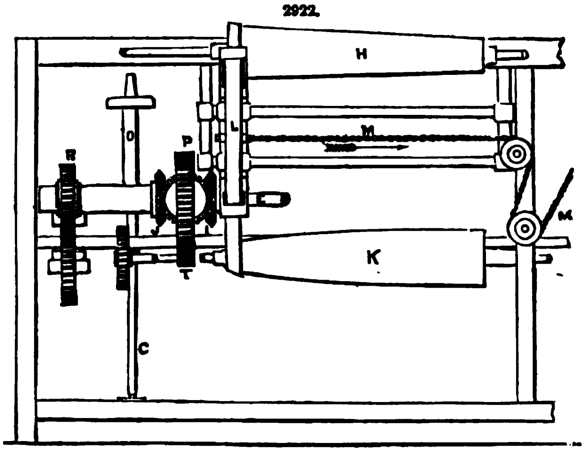
When the end of the roving is threaded through the flier D, and then attached to the bobbin-shank O, Fig. 2920, the flier being fixed upon the spindle C will first put the twist into the roving, according to the number of revolutions, generally from $1\frac{1}{2}$ to 2, which the spindle makes for each inch of sliver delivered by the drawing rollers B. Then the speed of the bobbin must be so much slower than that of the flier as to enable the flier by its greater speed to coil upon the bobbin the length of roving delivered by the drawing rollers. When one coil of roving has been laid upon the shank of the bobbin, its diameter is increased by double the thickness of the roving; and therefore before the next coil is wound on, the speed of the bobbin must be increased in proportion to the increased diameter. This is effected by each ascending and descending motion of the bobbin-lifter

N releasing a pawl, which allows the strap L to be drawn along the cones H and K to a different diameter, and thereby varies the speed of the pinion T gearing into the spur-wheel P. By this means the roving is wound upon the bobbin with an equal amount of tension, and consequently a uniform thickness, throughout the entire length wound. The different thicknesses of the roving, and consequently varying diameter of the bobbin when the coil is made with a thicker or thinner roving, are allowed for by the fineness of the teeth in the ratchet-wheel of the escapement apparatus. The bobbin-lifter N is counterbalanced by the weight U, Fig. 2920, and the vertical reciprocating motion is given to it by means of a mangle-wheel with pinion and rack V, driven from the lower cone K, so as to impart a gradually decreasing speed to the reciprocating motion of the bobbin-lifter, in accordance with the increasing diameter of the bobbin as the roving is wound upon it. These variations in speed can be so nicely adjusted that the bobbin will take up the whole length of the roving wound upon it, amounting to several hundred yards, without any perceptible difference in tension between the first coil and the last.

2921.



2922.



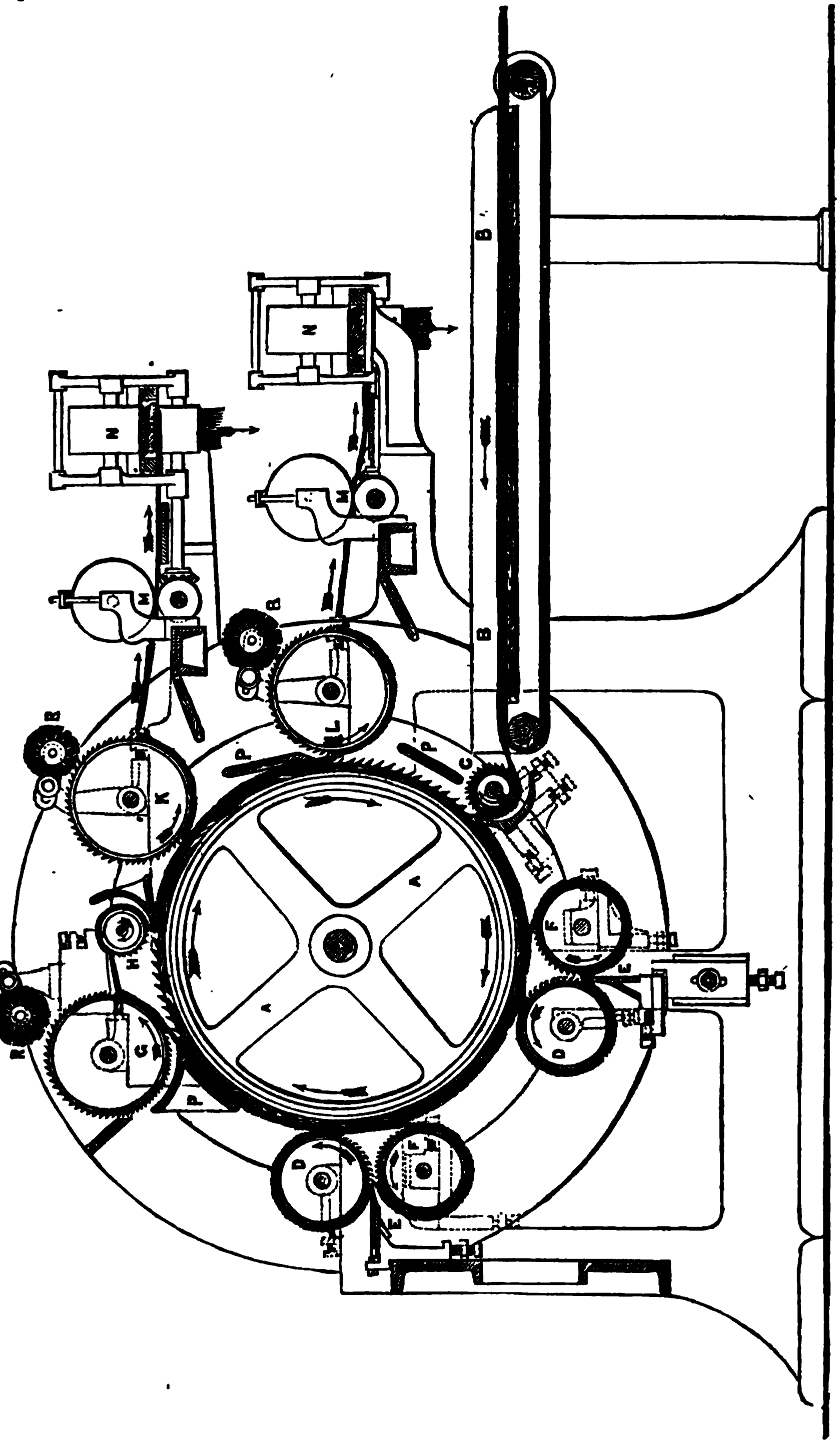
Figs. 2923, 2924, represent a section of a Tow Carding Machine. The tow frequently contains a considerable quantity of dirt and boom that has been left in the flax by the scutching machine. This is principally removed from the dressed line in the heckling process, but is thrown down with the tow or shorter fibres of flax which are combed out by the heckles. The tow carding machine is intended to separate the dirt and boom from the tow, and deliver the fibre in an even sliver ready for the drawing frame.

The large carding cylinder A, Figs. 2923, 2924, is 2 ft. 7½ in. diameter, and is made of cast iron, and covered with beech-lagging set with finely ground and hardened steel teeth. The tow is laid upon an endless feed-sheet B, which carries it forward to the feed-roller C. Under the feed-roller is a cast-iron shell, the upper edge of which is carried up into the angle formed by the carding cylinder and the feed-roller; and as the tow is slowly carried forwards by the feed-roller at a rate of about 2 ft. a minute, it is caught by the teeth of the carding cylinder A, which runs at about 300 revolutions a minute or 2500 ft. a minute speed of circumference. The teeth of the cylinder A throw the tow against the worker D, which is a slowly revolving roller, running at a surface speed of only about 100 ft. a minute, and covered with needle-pointed teeth set in strong leather. The teeth have a keen bend, as shown enlarged in Fig. 2924, and carry the tow round towards the iron bar E, the upper edge of which is polished. The tow is then caught by the stripper F, which is clothed in a similar manner to the carding cylinder A, and runs much quicker than the worker D but slower than the cylinder A, having a surface speed of about 1500 ft. a minute. The teeth of the carding cylinder then strip the tow from the teeth of the stripper F, and carry it forwards to a second pair of workers and strippers of exactly similar construction to the first, where the same operation is repeated for further cleansing and combing the tow.

The carding cylinder next carries the tow forwards to the doffer G, which is clothed with finely ground wire teeth set in leather, and moves very slowly at a surface speed of only 150 ft. a minute. The tow is combed off the doffer by a comb I, Fig. 2924, carried upon an oscillating arm worked by the crank-shaft J, and it passes forwards to the feed-roller H provided with an edge-plate or shell similar to the first feed-roller C, and running at the same surface speed as the doffer G, feeding the tow again on to the carding cylinder A. As the speed of the carding cylinder is so very much greater than that of the doffer and feed-roller, a further combing action takes place upon the tow, by the teeth of the carding cylinder combing out the fibres, which are partially held between the teeth of the slow-moving doffer and of the feed-roller. The carding cylinder then carries the tow forwards to the second and third doffers K and L, where the final combing of the fibre takes place; and from these doffers the tow is combed off as before by the combs I I, where it is divided into three slivers, and passed forwards to the two pairs of rollers M and N, in connection with which is a doubling plate provided with angular openings, as previously described in the spreading frame. The last pair of rollers N N deliver the slivers of tow into cans ready to be taken away to the drawing and roving frames. It is usual to place a gill drawing apparatus in connection with the carding machine, so as to perform the first drawing operation at the same time, immediately upon the slivers

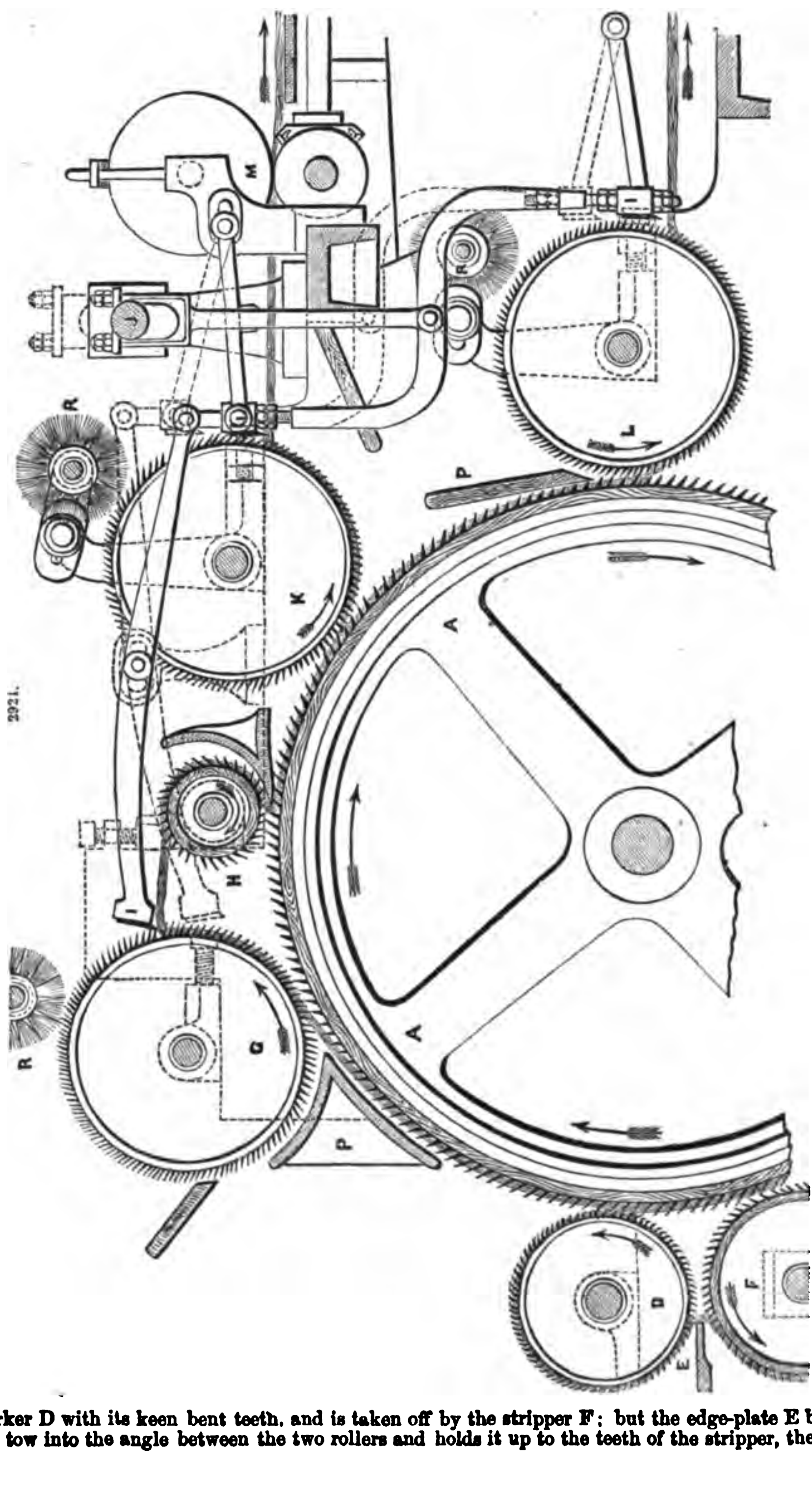
of tow being delivered from the last pair of rollers N N; and this arrangement has been adopted as an improvem

2923.



The action of the teeth upon the tow in the carding machine ought to be of a combing character, and in order to get this action the tow requires to be held up to the points of the teeth, which is

effected in the improved carding machine shown in the drawings by means of the edge-plates E E, Figs. 2923, 2924, inserted between the workers and strippers. The tow accumulates upon the

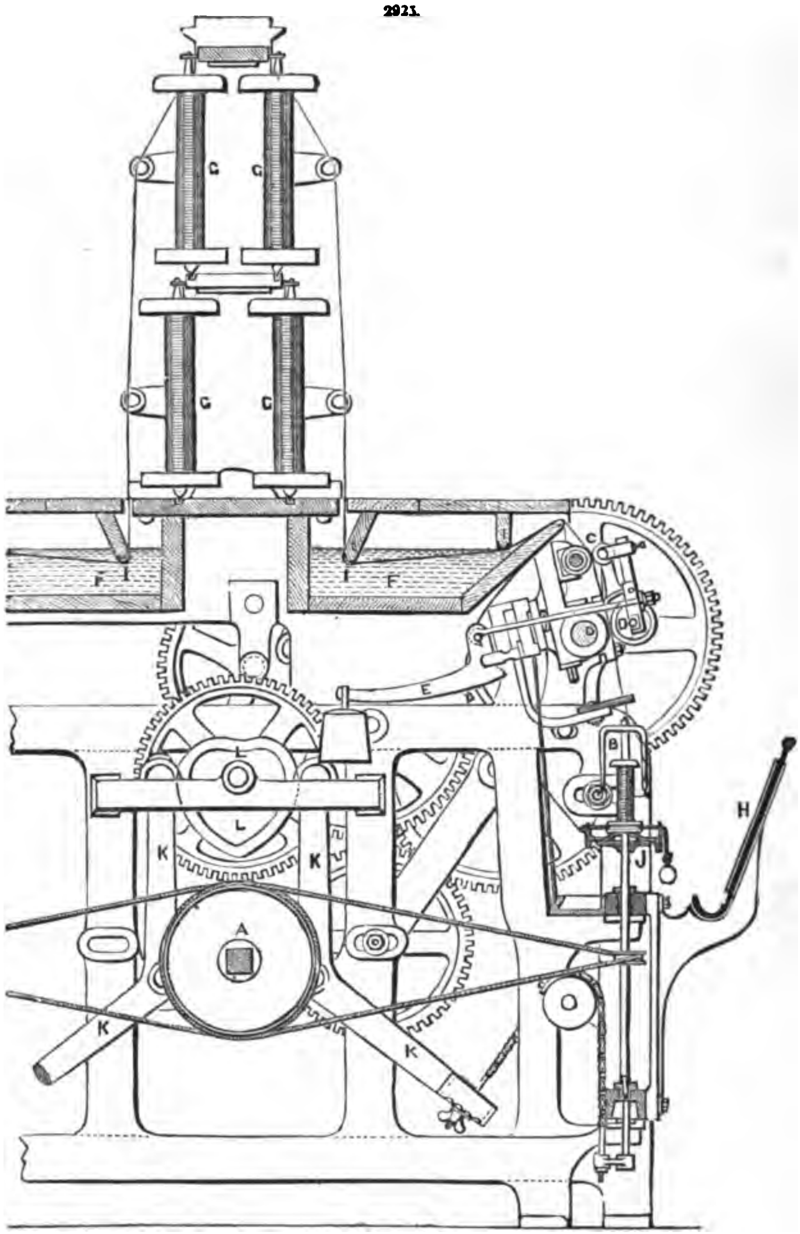


2921.

worker D with its keen bent teeth, and is taken off by the stripper F; but the edge-plate E binds the tow into the angle between the two rollers and holds it up to the teeth of the stripper, thereby

causing an amount of friction in the passage of the tow, and enabling the stripper by its quicker motion to comb out the fibres. In the ordinary carding machines, without these edge-plates between the workers and strippers, the tow is plucked in patches from the worker by the stripper, sometimes in such quantities as to roll up the tow, and in this state it is carried back to the carding cylinder, thus breaking the fibre and making uneven work. Carding machines have for a long time been made with cylinders as much as 5 ft. diameter, and a considerable number of pairs of workers and strippers, say from six to eight or even nine pairs; but in these the work produced is in no way

2921.



superior, and a much larger amount of waste is made and more power used. Wooden guards P P, Fig. 2923, are fixed in different positions round the circumference of the carding cylinder, for the purpose of directing the currents of air caused by the rotation of the cylinder so as to disturb the tow as little as possible in its passage between the points of the teeth of the several rollers running in contact with the carding cylinder, in order thereby to avoid waste and imperfect work. The teeth of the doffers G, K, and L, are kept clean by the brushes R R driven in the opposite direction.

The after processes of drawing and roving the tow slivers as delivered from the carding machine

are precisely similar to those in the long-line preparation already described, the drawing and roving frames for the tow being adapted to the shorter fibre to be worked. Several kinds of gills have been introduced for preparing tow, but none have proved an improvement upon the screw-gill, which is now almost universally used in flax machinery. The process of combing tow by a combing machine, after carding it, is carried on by two or three eminent spinners, but the cost is out of all proportion to the quality of yarn produced; and the tow thus prepared is only used for making sewing thread, to which it has been successfully adapted.

The last process in the manufacture of yarn is the spinning; and in Fig. 2925 is shown a transverse section of a wet spinning frame.

The cylinder A drives the spindles B, which carry the fliers for spinning the yarn, at a uniform speed of from 2000 to 4000 revolutions a minute, the speed being adjusted according to the weight and quality of yarn produced. C are the receiving rollers, and D the drawing rollers, which are called the back and front pair of rollers respectively; and the difference of speed is usually from eight to ten times, thus drawing out the roving to about $\frac{1}{10}$ of its size. The upper roller of each pair is pressed against the lower by the saddle and weighted lever E. The hot-water trough F through which the roving passes is placed with its edge as near as practicable to the bite of the receiving rollers C. The bobbins G from which the roving is supplied are placed above, and the roving is held down in the water by strips of wood I I faced with sheet brass. A splashboard H is fixed in front of the spinning frame, to prevent the spray from the wet yarn being thrown upon the attendants.

The lower of the two drawing rollers D is driven by a train of wheels from the main driving shaft A at a uniform speed of from 100 to 200 ft. a minute of the circumference, so that the fliers make from 20 to 40 revolutions for each foot of yarn delivered by the drawing rollers; and this additional amount of twist put into the wet sliver converts the delicate roving into a strong yarn. The yarn bobbin is loose upon the spindle B; and as the length of yarn given out by the drawing rollers is very much less than the length which the flier would wind upon the bobbin if the latter were stationary, the bobbin is simply dragged round by the flier in the same direction as the spindle B, without requiring any regulating gearing for driving the bobbin as in the case of the roving frame, since the yarn is too strong to be elongated or injured by the tension necessary to drag the bobbin round. In order to keep sufficient tension upon the yarn whilst winding upon the bobbin, so as to prevent *snarls* in the thread, a cord is pressed against a groove in the bottom flange of the bobbin, the friction of which retards the bobbin and produces the required tension upon the yarn; one end of this cord is fastened to the inner edge of the bobbin-lifter J, and the other end hangs pendent with a weight through a notch in the outer edge of the bobbin-lifter, which is notched along its entire length; thus the amount of friction upon the bobbin can be varied as desired by shifting the cord into a different notch, thereby varying the length of the arc of contact of the cord with the bobbin-flange. The bobbin-lifter J is raised and lowered at a uniform rate by the lever K worked by the cam L, which is driven from the main driving shaft A.

The important point in a spinning frame is to have good rollers. The receiving rollers C and the lower of the drawing rollers D are made of hard brass, and all three are very carefully fluted longitudinally with flutes that have a round top and bottom, so that the roving as it passes through the receiving rollers may not be unevenly crushed, which would cause the fibre to break down in the drawing process. The drawing rollers D have the upper or pressing roller made of soft material, usually boxwood, but the warm water used in the process is very destructive to the wood; gutta-percha also has long been tried, but if not well purified from sand or earthy matter it is apt to wear away the brass roller.

See the paper of Thos. Greenwood, printed in the Proceedings of the Inst. of M. E. (1865).

See Brake. Cotton Machinery. Gearing.

FLOAT WATER-WHEELS. Fr., *Roue à aubes*; Ger., *Schaufelrad.*

Before entering upon the examination of this subject, it is necessary to indicate the meaning of the letters that we employ in our calculations and investigations. Thus we have,

H = Total fall of the water. This fall, when it is taken to measure the entire force of the current, is the difference of level between the fluid surfaces of the upper and lower reaches. But for hydraulic wheels, it is reckoned from the upper level, or that of the reservoir, to the lowest point of the wheel, as this point may be lowered to the level of the lower reach, when this level is constant.

V = Velocity of the fluid on its arrival at the point of the wheel upon which it exerts its action.

v = Velocity of the wheel at the centre of percussion of the fluid. The distance of this centre from the axis of rotation is the *dynamic radius* of the wheel.

h = That portion of the fall comprised between the level of the reservoir and this same centre. It will be the height due to V, if this velocity experiences no loss between the reservoir and its arrival at the wheel.

h_1 = Height really due to V; thus, $h_1 = \frac{V^2}{2g}$.

We shall make $h_1 = h\,(1 - \mu)$, μ being a quantity connected with the before-mentioned losses.

h' = Height due to the velocity v; $h' = \frac{v^2}{2g}$.

h'' = Height due to the velocity $V - v$; $h'' = \frac{(V - v)^2}{2g} = \frac{(\sqrt{2gh_1} - v)^2}{2g}$.

P = Weight of water furnished in 1″ by the motive current.

Q = Volume of this same water. P = 62·45 Q.

K = Effort exerted by the motor upon the wheel.

p = Weight representing the sum of all the resistances which the motor has to overcome.

E = Dynamic effect produced by the wheel, or the force impressed upon it by the motor. $E = p\,v$.

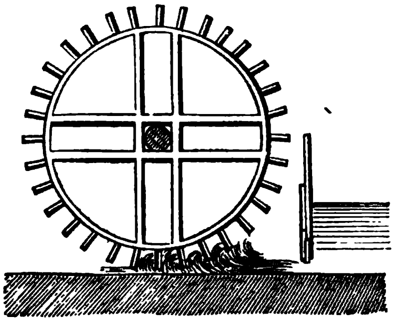
n = Ratio of the real to the theoretic effect, or to the impressed force deduced from calculation.

m = Ratio of the real effect to the force of the motor; $m = \frac{p\,v}{P\,H}$.

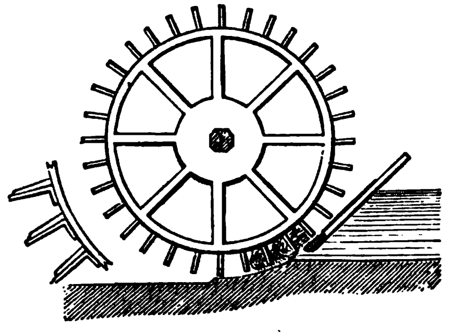
We are to treat here of what are strictly termed *float-wheels*. They are the most simple of wheels, and such as were formerly almost wholly in use; they are still in frequent use, principally on small falls, those below 5 ft.

Such a wheel, Figs. 2926, 2927, consists, 1st, of a *revolving shaft;* 2nd, of two rims or shroudings, and even of three in very large wheels; 3rd, of arms, which connect each rim to the arbor, and which are arranged in different ways, as we see by the figures; 4th, of supports, strong wooden pins, imbedded and held fast upon the shroudings; 5th, of floats nailed or bolted upon the supports; 6th, and quite often of counter-floats or planks fixed flat against the rims, and enclosing a part of the interval between the floats.

2926.



2927.



The motive water is led to the wheel by a water-course whose sides nearly touch the floats, leaving them only the play necessary for motion. It is delivered to the course through a gate-way, whose board is raised to a greater or less height, as we wish to deliver more or less water.

In the first place we shall make some observations upon the best disposition, and upon the principal dimensions to be given to parts which have an immediate influence upon the effect of the machine, to wit, the sluice, the course, and the floats.

The fluid mass, on its issuing from the gate, experiences a contraction; then dilating, it meets the sides of the water-course and follows them. Even should it have, when at the section of greatest contraction, a velocity due to the height of the reservoir, yet a notable portion is afterwards lost by the effect of this dilation, and that of the friction against the course, if it has any length; so that quite often it arrives at the floats with only three-quarters of this velocity. We prevent this loss of velocity, and consequently of force, 1st, by establishing the gate as near as possible to the wheel; we thus render the resistance of the course nearly insensible; 2nd, by disposing the sluice so as to reduce the contraction as much as may be; for this purpose, we prolong its bottom and lateral sides (above the opening) into the bottom and sides of the water-course; and we widen its entrance, or that of the canal which precedes it, so that the horizontal section of this entrance may have the form represented by Fig. 561; 3rd, we incline the gate-board and all the front part of the gate-way; this inclination amounts to carrying the orifice nearer the floats, and nearly approaches the openings of pyramidal troughs, where the contraction is almost nothing. Experiments made by M. Poncelet place beyond a doubt the good effect of this inclination; a gate inclined 63° to the horizon (1 base to 2 height), gave him 0·75 for the coefficient of contraction, and he had 0·80 with an angle of 45° (1 base to 1 height); an upright gate, in the same circumstances, gave about 0·70. By disposing his sluices in the manner above indicated, this philosopher accomplished the end of bringing the motive current upon the floats of the wheel with a velocity but little differing from that due to the height of the reservoir; it is true that the opening of the gate was great, and the diminution of the velocity is as much the less as the opening is more considerable. If, without loss of fall, we might direct the water immediately upon the floats, in causing it to issue through an orifice in a thin plate, or through a pyramidal trough, the velocity would experience only a few hundredths of diminution.

Immediately past the gate, the water-course is directed, with a slight inclination, towards the wheel; it passes beneath, and then continues in a right line, Fig. 2926. Its size is determined by the volume of water which it is to conduct; the thickness of the fluid sheet in the water-course (supposing for an instant the wheel to be raised up) should never be above 0·82 ft. nor below 0·49 ft. If it were less, the quantity of water escaping between the flooring and the lower edges of the floats, without exerting any action upon them, would be proportionally too great; and the force of its current would be notably diminished. That this diminution may be as slight as possible, we should not give to the space necessary to be left between the sides of the water-course and the edges of the floats more than from ·0328 to ·0656 ft.

If ever so little attention is given to careful constructions, we do not make the water-courses entirely rectilinear. Their bottom or flooring should arrive at the level of the lower edge of the second float above the vertical diameter; there it curves concentric with the wheel, as far as the plumb line of this diameter; then it falls suddenly a decimètre (·328 ft.) at least, and finally

pursues its course with the slope permitted by the locality, Fig. 2927. Its breadth, immediately before reaching the floats, is a little less than theirs; it then increases and encloses the floats beyond the vertical diameter. By these dispositions, the water, on its arrival at the wheel, impinges upon it with all its mass, without experiencing a loss through the intervals: after that the lowering and enlargement of the wheel-course favours the clearing of the water, and does not obstruct its motion.

After what has just been said, the breadth of the floats is fixed by that of the course, and by the size of the intervals. Their height, in the direction of the arm of the wheel, ought to be such that in the greatest rising of the water against the first float struck by it, a portion of the fluid, which tends to run past its upper edge, although retained by the counter-float, shall not lose a part of its action: we prevent this loss by giving to the height of the floats about three times the thickness of the sheet of water in the course, without, however, exceeding 2·13 ft. The distance from float to float, measured upon the exterior circumference of the wheel, should be a little less than their height.

Their number, then, will depend upon the extent of the circumference or of the diameter, and this dimension is nearly arbitrary.

The dynamic effect of the wheel is proportionate to the velocity of the floats: it requires only this velocity, which is independent of the diameter. When the diameter is required, we usually determine it by the number of turns which it is proper the wheel should make in a certain time, in order that the transmission of motion to that part of the machine which does the useful work, and which should consequently have a certain velocity, should be effected with the greatest simplicity, and with the least gearing possible. This is accomplished in such a way that the wheel shall have a velocity and dimensions adapting it to fulfil the office of a *fly-wheel*, so as to maintain a suitable uniformity of motion. If u is the velocity at the extremity of the floats, N the number of turns wished in a minute, the diameter will be $\frac{60\,u}{\pi\,N}$, or $19\cdot 1\,\frac{u}{N}$. For the case of good effect, we shall have nearly $u = 3\cdot 08\,\sqrt{H}$; and consequently the diameter will be $\frac{58\cdot 8}{N}\,\sqrt{H}$. Finally, in practice we never make it less than 13·12 ft., nor more than 26·25 ft.

According to the adopted size of the diameter, we shall give to the wheel the number of floats indicated below. This number is divisible by 4; from the fact that constructors are in the habit of putting an integral number of floats in each of the four quarters of the wheel. We may, besides, without any disadvantage, increase by 4 each of the numbers of the Table.

Diameter.	Floats.	Diameter.	Floats.
ft.	No.	ft.	No.
13·12	28	22·97	40
16·40	32	26·25	44
19·68	36		

Bossut, in raising the same weight by a small wheel of 3·346 ft. diameter, sometimes with 48, at other times with 24 floats, obtained effects which were in the ratio of 4 to 3, whence he concluded that it would be better to give a greater number of floats to wheels than is usually done. But his water-course was rectilinear, and in such a course the wheel takes positions in which the spaces between the flooring and the edge of the floats shall be the greater as their number is the smaller: whence it follows that a great quantity of water is lost without exerting any action. Smeaton, to whom this fact was well known, remarked that this no longer occurs, and that the effect is not necessarily diminished by lessening the number of floats, when we curve the flooring concentrically with the wheel, and that it was sufficient to give such a length to the curved part, as that one float might enter it before the other left.

Some mechanists have supposed that the dynamic effect is increased by inclining the floats upon the direction of the arm, and they have given them such an inclination. But what may be advantageous for a wheel plunging in an indefinite fluid is no longer so for one established in a mill-race. Bossut having compared the effects obtained with floats inclined 0°, 8°, 12°, and 16°, found that they were respectively as the numbers 1, 0·949, 0·956, and 0·998; so that in these experiments, the only ones with which we are acquainted, the inclination has been a disadvantage.

In the case only where a wheel might casually be plunged in the race of a canal (for we cannot admit that it is usual, inasmuch as its establishment then would be faulty, and would have to be changed), the inclination of the floats would favour their clearance; or rather, it would prevent the floats, after they had passed the vertical, from taking up and raising a certain quantity of water, which, acting in a direction opposite to the motion, would diminish the effect. This inconvenience is obviated in large wheels established upon the arms of a river, where the fall is very small, and where the floats are composed of different pieces, by giving them a slight inclination, but more and more as they approach the exterior circumference of the wheel.

Attempts have been made to increase the dynamic force, by means of lining the floats with borders or side pieces. But their action was inconsiderable in the case where the paddles which receive the impulse of the fluid are placed in a water-course. It will be still less upon the floats of a wheel; and in the experiments of M. Poncelet, made at a powder-mill in Metz, these flanges have augmented the effect but a fifteenth.

We produce, and with more certainty, an analogous effect, by fixing and enclosing the floats between two circular plates, similar to those which form the crown or shrouding of bucket-wheels.

In narrow wheels, cast-iron floats, slightly cylindrical, the axis of the cylinder being in the direction of the radius, produce the effect of these side enclosures.

When we put in motion a machine at rest, and for this purpose open the gate, the fluid is precipitated forcibly against the float which is opposite to it, rises and flows over all its parts; continually pressed by that which arrives without interruption, it exerts a greater effort than when the motion is established. A portion of this effort is put in equilibrium with that of the resistances to be overcome; the remaining portion acts, in the first moment, to break the adhesion contracted during the repose by the pieces of the machine which should move upon each other; and then, striving against the inertia of the masses, it accelerates more and more its motion. As the velocity of the wheel increases, its action becomes more feeble (since this action is proportional to the relative velocity); soon the acceleration, diminishing gradually, becomes insensible and as nothing; and the wheel, after a few turns, in consequence of the velocity impressed upon it, and in virtue of its inertia, continues to move, as it were, of itself, either with an entirely uniform motion, or with a velocity which, oscillating between near limits, may be reduced to a mean and continuous velocity.

The action of an impulse, or the dynamic effect produced by it upon the floats of a wheel, or, more exactly, upon a paddle well set in a water-course, and which yields perpendicularly before the fluid, is $\frac{P}{g}(V - v)v$.

Is it the same for a series of floats presented in succession to the current, or two or three at a time, and under different angles of inclination? Experience alone can afford us just ideas upon this subject: meanwhile, we assume that the action of the impulse upon the wheel is not equal, but of the same nature, and having the same form of expression as the above.

In this expression of effect, when the wheel is moved by the same current, v is the only variable. If $v = 0$, the effect will be nothing; a machine which does not move cannot produce any. It will still be nothing when $v = V$; a wheel which goes as fast as the current cannot receive action from it. It is moreover evident that v can never exceed V. So that the effect will increase according as the velocity of the wheel, starting at zero, shall increase; but only up to a certain point, beyond which this effect will decrease, returning to nothing when the velocity shall be equal to V; between these two extremes there will, then, be a *maximum* of effect. Differentiating the variable part of the expression, $(V - v)v$, and making this equal to zero, we have $V\,dv - 2v\,dv = 0$; whence $v = \frac{1}{2}V$; that is to say, that *a wheel with floats produces its greatest effect when its velocity is half that of the current.*

The effort of the water upon the float is $\frac{P}{g}(V - v)$; this will also be the value of the load of the machine, that is to say, of the sum of resistances which it can overcome, these quantities being equal.

For the case of *maximum* of effect, where $v = \frac{1}{2}V$, this load will be $\frac{PV}{2g}$. For the same case, the dynamic effect, being equal to this load multiplied by its corresponding velocity $\frac{1}{2}V$, will be equal to $\frac{PV^2}{4g}$, or, observing that $\frac{V^2}{2g} = h_1$, $\frac{1}{2}P h_1$. The greatest effect of which a current arriving at a machine is susceptible, with P of water, and a velocity due to h_1, is $P h_1$; that of a wheel with floats will therefore be only half of this. If the entire fall H had been made available, and experienced no loss of velocity, either at the gate or in the course, we should have $h_1 = H$, and for the *maximum* effect $\frac{1}{2}PH$. Whence we conclude, *that the greatest effect which can be produced by a current of water acting by its impulse upon a wheel with floats, and upon a hydraulic wheel in general, is but half of the greatest effect of which it is capable.* And yet we could never have arrived even to this half, but through suppositions which are not realized; it is a limit which we cannot attain, and from which we are usually far removed, as we shall soon see.

We pass to the modifications which experience must make in the results of a theory, which, moreover, we have only admitted with reserve. We shall devote some time to this subject, both because we are dealing with nearly the only wheel that is moved solely by the impulse of water, and because the field of experiment has been successfully explored by a man of superior merit, Smeaton. His observations were made, it is true, on a small scale, the model of the wheel being only 2 ft. in diameter; but they were so well directed towards the principal points of the problem to be solved, and executed with so much skill, that they enable us to recognize the principal circumstances of the motion of wheels with floats. It was only after Smeaton had satisfied himself that their results were conformable with those observed by him on large wheels, that he published them.

Upon the axle of a wheel a cord was wound, which passed over a pulley on the top of the machine, and which bore at its end a basin, in which were placed at pleasure various weights. The water was furnished to the wheel by a reservoir, which was constantly kept at the desired height.

The experiments were divided into classes and series: those of the same class all have the same opening of the sluice-gates; and in those of the same series, they moreover had the same height of reservoir, and consequently the same quantity and the same velocity of motive water, or the same dynamic force. The velocity of the fluid, at the moment of striking the wheel, as well as the passive resistances, were determined previously and directly by experiments of a very ingenious character, which may be found in the memoir of the author. These preliminaries having been established, a small weight was at first put in the basin; when the motion was well established and had become uniform, they counted the number of turns made by the wheel in 1′ or 60″, and thence deduced the velocity of the elevation of the weight: this was the first experiment of the series. Then the basin was lowered, and a heavier weight placed in it, and the time of raising it was taken. So, in succession, for a third, fourth, &c., weight, up to the weight which was so heavy

as to arrest the motion; the series of experiments was then completed. That term in which the product of the weight raised (adding to it the weight representing the passive resistances) into the respective ascensional velocity, was found to be the greatest, was the term of *maximum effect* of the series.

Smeaton in this manner made twenty-seven series of experiments, and he published a table presenting the circumstances relating to the experiment of *maximum* of effect in each series. The following Table, containing eighteen of these experiments, is an extract from it. The dotted transverse lines to be seen in it separate the six classes of experiments; from one class to the other the opening of the sluice-gate was gradually enlarged. The titles of the columns indicate their contents sufficiently well. We confine ourselves to the remark that, for each experiment, $h_1 = \frac{V^2}{2g}$, $H = h_1 \frac{\alpha}{\beta}$, α being the number of the experiment or of the horizontal line noted in the eighth column, and β the number in the ninth; H is the height of the water above the gate sill; $\psi = p\gamma$, γ is the corresponding number of the tenth column, and ψ represents, for each series, the weight which, put in the basin, would arrest the wheel.

Water expended in 1″. P	Velocity of Current. V	Velocity of Wheel. v	Weight raised. (Resistance.) p	Effect. pv	Coefficient concluded. n	Ratios. $\frac{v}{V}$	$\frac{pv}{Ph_1}$	$\frac{pv}{PH}$	$\frac{\psi}{p}$
lbs.	ft.	ft.		lbs. ft.					
4·583	9·166	3·125	·6336	1·98	0·74	0·34	0·32	0·16	1·30
4·05	8·541	2·916	·4972	1·45	0·71	0·34	0·32	0·17	1·33
3·566	7·812	2·698	·3784	1·021	0·67	0·35	0·30	0·16	1·37
2·975	6·77	2·437	·2519	·614	0·64	0·36	0·29	0·17	1·20
2·233	5·416	1·979	·1495	·296	0·63	0·37	0·29	0·18	1·11
1·9	4·375	1·666	·0972	·1620	0·61	0·38	0·28	0·16	1·08
5·7	8·75	3·203	·6525	2·090	0·66	0·37	0·31	0·18	1·27
4·75	7·50	2·708	·5000	1·354	0·72	0·36	0·33	0·19	1·15
3·9	6·56	2·604	·2922	·761	0·61	0·40	0·29	0·20	1·15
2·79	4·79	2·187	·1344	·294	0·60	0·45	0·30	0·21	1·11
5·95	7·499	3·02	·5579	1·685	0·68	0·40	0·32	0·23	1·25
5·50	6·874	2·786	·4379	1·219	0·63	0·41	0·31	0·22	1·24
3·80	4·999	2·447	·1798	0·440	0·62	0·49	0·30	0·23	1·04
5·981	7·08	2·812	·4967	1·397	0·63	0·40	0·30	0·24	1·09
4·366	4·999	2·551	·2093	0·534	0·63	0·51	0·31	0·24	1·08
5·916	6·249	2·843	·3823	1·087	0·61	0·46	0·30	0·24	1·06
5·116	5·208	2·562	·2439	·625	0·58	0·49	0·29	0·24	1·06
6·00	5·208	2·708	·2736	·741	0·64	0·52	0·30	0·25	1·08
1	2	3	4	5	6	7	8	9	10

The first four columns of the Table present the data of the experiment; the last six, the results deduced from them. Let us sum up these results.

A glance at the sixth column shows that the coefficient of reduction of the theoretic effect to the real effect is not constant, and consequently that the admitted theory does not adapt itself to all the circumstances of the movement of wheels with floats.

Its results, as to effect, are so much farther from those of experiment, as the velocity is more considerable, as we may see in the Table following, which answers to the only entire series of experiments which Smeaton has given us. The quantity of motive water used there was 4·46 lbs and its velocity 9·222 ft.

v	pv	n	v	pv	n
ft.	lbs. ft.		ft.	lbs. ft.	
4·691	1·512	0·52	3·117	1·751	0·67
4·363	1·671	0·57	2·756	1·714	0·69
3·773	1·671	0·59	2·296	1·967	0·71
3·510	1·765	0·64	1·706	1·280	0·71

The coefficient n does not present so great varieties in the experiments of the great table, which answer to the *maximum* of effect of each series: and even, making abstraction of some anomalous numbers, we have for the mean of each class (one only excepted) very nearly $n = 0{\cdot}64$; and consequently, E or $pv = 0{\cdot}64 . \frac{1}{2} P h_1 = 0{\cdot}32 P h_1$.

This ratio of $p v$ to $P h_1$, immediately given by each experiment, is noted in the eighth column of the Table; it only varies from 0·28 to 0·32; and the mean term has nowhere exceeded 0·30. Nevertheless, Smeaton thought he had good cause to raise it as high as $\frac{1}{3}$ for great wheels; that is to say, to admit their effect to be $\frac{1}{3}$ of the force which the current possesses on its arrival at the floats.

The ratio of this same effect to the entire force of the motor, or m, indicated in the ninth column, is not so constant in its character as the preceding; it gradually increased from one class to the other, from 0·167 up to 0·25. So that, in the experiments of Smeaton, *the greatest dynamic effect was only from a sixth to a quarter of the entire force of the motor.* We doubt if in great machines, even supposing them well arranged, it attains this last value; though theory indicates it as double, or $\frac{1}{2}$ P H.

The ratio of the velocity of the wheel to that of the current gradually increased from one class to the other, that is to say, in proportion as the opening of the sluice-gate was greater, from 0·36 up to 0·52; it was, as a mean, 0·44. Smeaton does not admit over 0·40. Bossut, after a series of some experiments, also adopted this same number; but as the velocity of the current was measured at the surface, they have given too small a result; it would approach 0·50 in taking the mean velocity. We believe that in machines well arranged and well conducted we may very nearly attain this theoretic limit; and, with some authors, we shall adopt $v = 0·45$ V, always for the case of *maximum* of effect.

Finally, the last column shows that the load which arrests the wheel is only from one to two tenths greater than the load for the *maximum* of effect. But according to theory it should be double; indeed, the load ψ, corresponding to the velocity $v = 0$, is $\frac{PV}{g}$; and that which corresponds to the *maximum* is $\frac{PV}{2g}$, p. 1514.

The results we have just given refer to the case where the velocity of the wheel is found to be the most advantageous ratio to that of the current at the moment of striking the floats. But usually this is not the case; the effect is less, and its coefficient n, experiencing great variations, as we have seen in the small Table (p. 1515), can never be expressed by a general formula.

However, when the velocity of the wheel does not exceed certain limits, one-third to two-thirds that of the current, without the risk of any notable error, especially in excess, we may take ·60 for the coefficient, and admit

$$E = 0·60 \frac{P}{g} (V - v)\, v = ·01864\, P\, (V - v) v = 1·1640\, Q\, (V - v)\, v.$$

The velocity V, with which the water arrives at the floats, is always difficult to determine. It meets, as we have seen (p. 1512), with losses between the sluice-gate and the wheel; without them, we should have $V = \sqrt{2 g h}$; and h, the difference in level between the surface of the reservoir and the centre of percussion of the floats, would be easily measured.

Smeaton, who made observations upon the losses really experienced, and who has sometimes seen them as high as one-fifth of the velocity, has also remarked that they diminish, when the height of the opening of the gate increases; so much, says he, that in mill-sluices, when great volumes of water are discharged, under moderate heads, V will be very nearly equal to $\sqrt{2 g h}$. M. Poncelet has also observed that the loss of velocity is less in great openings; and that through an opening ·7217 ft. in height, and even with a head of 4·593 ft., he found $V = 0·99 \sqrt{2 g h}$. Still, to prevent mistakes, and supposing that the sluice-way is otherwise suitably arranged, we will admit $V = 0·95 \sqrt{2 g h} = 7·6215 \sqrt{h}$; and consequently we shall have generally $E = 1·1642\, Q\, (7·6215 \sqrt{h} - v)\, v$. When v is very near to $\frac{1}{2}$ V, this expression will be reduced to $E = 16·907\, Q\, h$.

The ratio between the effect and the entire force of the motor will be established in a manner still less sure. Smeaton, even in the case of *maximum* effect, found it vary from 0·16 to 0·25. So that we shall have nearly always $E < 0·25$ P H or $< 15·612$ Q H.

Finally, we but little regret our inability to give a more precise expression of the effect of wheels with floats moved by the impulse of water, inasmuch as this kind of wheel is nearly out of use.

Notwithstanding this remark, suppose we are to establish a wheel to put in action a blast-engine, appointed to throw into a high furnace for melting iron by means of coal or of coke, three-quarters of a cubic mètre or 26·487 cub. ft. of air in a second, with a velocity of 426·51 ft.; and that we have upon a small river a fall of 5·4134 ft. We wish to determine the volume of water required to move the machine.

That we may have three-quarters of a cubic mètre of air in the furnace, in view of the inevitable losses, we must count upon a cubic mètre. At the level of the sea, and at zero of the thermometric temperature, it would weigh 2·8671 lbs.; at the site of the mill it will weigh only 2·6906 lbs.; we will admit 2·7568 lbs. The height due to the velocity of 426·51 ft. is 2821·57 ft. Thus the useful effect to be produced is equivalent to raising 2·7568 lbs. to a height of 2821·57 ft., or 1075 km. = 7778·59 lbs. ft. in one second. By reason of the passive resistances of the wheel, of the machine and air-pipe, we will augment this number by a third, and we shall have for the dynamic effect, 10371·45 lbs. ft. = E.

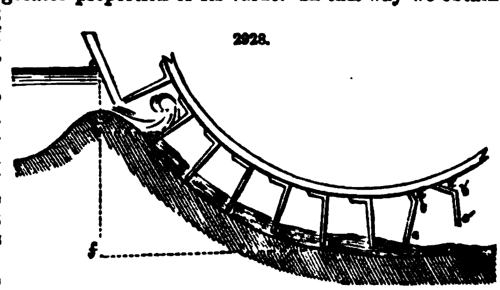
On the fall of 5·4134 ft., we will take ·98427 ft. for the distance between the centre of percussion of the floats and the lower level; and there will remain but 4·4292 ft. for the value of h. Thus the equation will be $10371·45 = 16·907\, Q \times 4·4292$; whence $Q = 138·49$ cub. ft. We will reckon upon 141·266 cub. ft. This water, having to run in a water-course with a velocity of 16·04 ft. $= 7·6215 \sqrt{4·4292}$, the section of the fluid sheet in it will be 8·888 sq. ft., and as its thickness should not exceed ·6562 ft., its breadth must be 13·418 ft.; let us put it at 13·45 ft.

Leaving a space ·0492 each side between the course and the wheel, we shall have for the breadth of the latter, that is to say for the breadth of the floats, 13·353 ft. Their height will be 2·132 ft.; for under the wheel, the water will rise 1·97 ft. and more: they will therefore be furnished with counter-floats ("*contre-aubes*"). Their number will be forty, the diameter to be given to the wheel being 20·34 ft.; each will be formed of four planks, ·574 ft. wide, and inclined gradually upon the radius 0°, 10°, 20°, and 30°; the three iron supports to hold them will have three bends or angles of 170°. The wheel will make about seven turns per minute, and its motion will be communicated without gearing to the pistons of the blast-cylinder, either by means of cranks, winches, balance-beams, or by cams, in the form of eccentric wheels, which will accompany them in their ascent and descent.

The float-wheel just described, exceeding 13 ft. in width, consuming 141·26 cub. ft. of water per second, with a fall of 5·413 ft., having thus a force equivalent to 89 horse-power, will be one of the most efficient which we can have. If charcoal were used in the furnace, we should not require over 17·66 cub. ft. of air per second, with a velocity of 328 ft. A volume of water of 44·14 cub. ft. would be sufficient to move the wheel. We should give it a width of only 4·92 ft.; its floats might be plane and 1·968 ft. deep.

Wheels established in a Circular Water-course or Curb.—We have seen, p. 1512, that the most advantageous disposition of the course for float-wheels is in curving it under the lower part of the wheel and concentric with it, for a short length (one or two of the float spaces), and consequently a very small height. The advantage increases as the height or versed sine of the curved part is greater; so much so, that now they are made as great as possible compared to the fall; and we give them two-thirds, three-quarters, and even a greater proportion of its value. In this way we obtain wheels of very good effect, perhaps the best that can be had with small falls, those of 8 ft. and less. Fig. 2928 gives a good idea of their disposition.

2928.



Manifestly, the circular course or curb should be constructed with great care, and of masonry, if possible; its apron, or cylindrical surface, should be very smooth, well centred, and so that its axis shall be exactly the axis of rotation of the wheel which the *curb* or *mantle* encloses. The space to be left between its surface, that of the bottom as well as its sides, and the edges of the floats, should be from 0·0328 ft. to 0·049 ft. We should never make them less; in the best suspended and best made wheels, after a while, some portions yield or wear out, some joints begin to play; and if the space is too small, the floats will soon rub and scrape against the curb. This consideration should induce us to establish very solidly the walls or pillars upon which the *gudgeons* are supported. The breadth of the course, as well as that of the wheel, should be such that the water, running freely over its bed, might not have a depth of over 0·656 ft., nor under 0·049 ft. The diameter of the wheel will be determined in the manner and according to the considerations shown in p. 1513; generally it is from 16·4 ft. to 23 ft. The number of the floats will be such as before described, p. 1513. Their height should never be less than three times the thickness of the fluid sheet of water in the course. They should be placed in the direction of the radius. Still, good millwrights give them a slight inclination; quite often they incline them to the radius with an angle $90° + a$, a being given by the equation $\cos. a = 1 - \frac{2\,\mathrm{H}}{\mathrm{D}}$. Sometimes they give the forms indicated in Fig. 2928 by $a\,b\,c$, or $a'\,b'\,c'$. The sluice-gate should be made and disposed with all the precautions indicated in p. 1512, and in such a manner that the water should fall very nearly perpendicular upon the float receiving the impulse. Better still, if it can be done, when we cause the water to fall by simply flowing over a sill established at the top of the curved apron.

Water acts upon wheels established in such a course, both by its impulse and by its weight. If from the point e, Fig. 2928, taken at the surface of the reservoir, we drop the perpendicular $e\,f$, upon the horizontal line passing through the bottom of the wheel, and let k be a point taken at the level of the one where the water arrives at the first float struck; $e\,f$ will represent the total fall H, and $e\,k$ the portion h of this fall employed in the generation of the velocity with which the impulse is made. After this has taken place the water spreads out upon the float, descends with it pressing upon its upper surface; so that the fluid which is in the course, throughout the whole height $k\,f$, presses upon all the floats found there, and urges them in the direction of motion; this action of the weight will be expressed by $\mathrm{P} \times k\,f$ or $\mathrm{P}\,(\mathrm{H} - h)$. The action of the impulse is expressed by $\frac{\mathrm{P}}{g}\,(\mathrm{V} - v)\,v$, or $\mathrm{P}\,(h - h' - h'')$; or, more exactly still, with the notations, p. 1511, and according to what we shall hereafter establish (see OVERSHOT WATER-WHEELS), by $\mathrm{P}\,(h - \mu\,h - h' - h'')$, $\mu\,h$ referring to losses experienced in the velocity of the current between the gate and the wheel. Uniting these two partial actions, the total action, or the effect $p\,v$ which results from them, will be

$$\mathrm{P}\,\{(\mathrm{H} - h) + h - \mu\,h - h' - h''\}.$$

We have two corrections to be made for this expression.

First, even when all the water P expended shall have acted by its impulse upon the first float it meets; beyond that, when it descends in the course, pressing upon the succeeding floats, the part of the fluid which is found in the intervals between the edges of the floats and the sides of the course exerts no pressure, and has no effect; and consequently it should be subtracted from P in

the expression $P(H - h)$. The amount of this part cannot be rigorously determined. Still, if we consider, 1st, that the resistance experienced by this water against the sides of the course diminishes the velocity which gravity tends to give it, more and more during its descent upon the bed of the curb; 2nd, that this velocity is still more diminished by the continual obstructions which the water meets in its passage through the spaces, varying at each instant, for a wheel is never perfectly centred; 3rd, finally and especially, that the velocity is altered by a continual mingling of the water in the spaces with that resting upon the floats, we may conceive that in nearly every case, the velocity of one will be that of the other, and consequently equal to that of the floats. In such a case, if we designate by A the section of the fluid sheet in the course, and by a that which answers to the spaces, $P\frac{a}{A}$ will be the portion of the fluid which produces no effect; we must deduct this from P in the expression of effect, which will become $P\left(1 - \frac{a}{A}\right)(H - h)$.

Secondly, the portion of the bottom of the wheel which plunges in the water of the course, there loses a part of its weight equal to the weight of the fluid which it displaces. In consequence of this loss, there does not exist an equal distribution of the weight of the wheel around the axis of rotation; and the wheel tends to turn against the current; let p' be the weight representing the effort of this tendency; this will be a new resistance which the motor must overcome, and it should be added to the other efforts or resistances of which the sum is p. We have then, n being the coefficient of reduction of the results of calculation to those of observation,

$$(p + p')v = nP\left\{(H - h)\left(1 - \frac{a}{A}\right) + h - \mu h - h' - h''\right\}.$$

The example which we shall shortly give will show us the manner of applying this formula.

For common use, it may be simplified. The quantities p' and $1 - \frac{a}{A}$, supposing the constructions equally well made, will be very nearly proportional to the force of the machine, or to P; and they may consequently be comprised in the value of n. Moreover, we shall see (OVERSHOT WATER-WHEELS) that the quantity $\mu h + h' + h''$ always exceeds $\frac{1}{2}h$, and that it is very nearly $\frac{3}{4}h$. So that the equation is simply $E = nP(H - \frac{3}{4}h)$.

Let us determine the coefficient n. Let us see its value in a machine, perhaps the most perfect of the kind we have discussed; it is a wheel established at the crystal-ware manufactory of Baccarat, near Lunéville, by English constructors, and similar to those in use in their country. It is 13·14 ft. in diameter, with a breadth very nearly the same; it has 32 floats 1·312 ft. deep; and it is hung in a circular course, 6·037 ft. versed sine, upon a fall of 6·758 ft.; the space between the sides of this course and the edges of the floats is reduced to some millimètres, says M. Morin. The motive water was let upon the wheel over a weir 12·79 ft. long, with the head h_0 above the lip noted in the following Table. According to the experiments of M. Castel, the volume of water discharged will be $3·5567 \times 12·79 h_0 \sqrt{h_0}$; whence we have the values of P. The fall was 6·037 ft. + h, and we have represented by H' the factor $H - \frac{3}{4}h$. As for p, the sum of the resistances to motion, it is the result of experiments made by M. Morin, by means of a dynamic brake: to the effort immediately indicated by the brake, this author has added the passive resistances, which he determined by calculation; finally, as they do not reach to $\frac{1}{12}$ of p, a little uncertainty respecting them would be but of small consequence.

v	p	P	h_0	$\frac{pv}{PH'}$	$\frac{pv}{PH}$
ft.	lbs.	lbs.	ft.		
7·64	108·04	1726·8	·7185	0·762	0·707
3·805	227·10	1740·1	·7217	0·792	0·734
3·182	269·06	1740·1	·7217	0·783	0·726
2·723	306·50	1715·8	·7152	0·777	0·720
2·395	348·40	1715·8	·7152	0·773	0·716
2·132	385·90	1726·8	·7185	0·755	0·700
Mean		1727·5	·7184	0·772	0·717

Thus, for the machine at Baccarat, n would be, as a mean, 0·772. But we rarely meet a wheel with so small a play as this, and it will only be for machines very carefully constructed and maintained that we can admit $E = 0·75P(H - 0·7h)$. The above experiments give 0·717 for the ratio of pv to PH. But where, as for the wheel upon which they were made, shall we find the height of the circular curb so great as $\frac{9}{10}$ of the fall? Most frequently this height, or more exactly that upon which the water only acts by its weight, is not over one-third, and we generally have from 0·60 P H to 0·65 P H. In the application, we shall not use these expressions, but the preceding, $0·75P(H - 0·7h)$; diminishing the numeric coefficient a little if the machine is in an ordinary condition.

Upon a canal fed by a river we have an iron-mill, to which we wish to add a rolling mill of thirty horse-power. The available fall at low water is 8·202 ft.: we will employ a wheel moved by the weight of the water. It is required to indicate the volume of water necessary to put it into action, and the principal dimensions to be given it.

We require for the working of the rollers that the wheel should make six turns per minute, with a velocity of 7·38 ft. Accordingly, its dynamic radius should be 11·745 ft. (p. 1513), and we

will make the whole diameter 24·278 ft. It shall be a wheel with floats, of which there shall be forty-eight, and formed of two planks; the small one will be placed in the direction of the radius, and will be ·722 ft. in height; the greater will make with it an angle of 160°

$$\left(= 90° + 70°;\ 1 - \frac{2\,\mathrm{H}}{\mathrm{D}} = 1 - \frac{15·748}{24·278} = \cos. 69° 27'\right),$$

and we will give it a height of 1·397 ft., so that the two united shall make 1·968 ft. in the direction of the radius. The counter-floats will be 1·148 ft. in breadth. We will sacrifice ·328 ft. of the total fall for lowering the apron immediately below the wheel. The height H will then be 7·874 ft. We take from this 6·562 ft. for the height of the curve to be given to the circular part of the course, and there remains 1·312 ft. for h; thus $\mathrm{H} - h = 6·562$ ft. We have seen that $\mu h + h' + h''$ was greater than $0·5\,h$, and we have made it $0·7\,h$; consequently,

$$h - \mu h - h' - h'' = 0·3\,h = ·3936 \text{ ft.}$$

After this, the equation will be $(p + p')\,7·382 = 0·90\,\mathrm{P}\left[6·562\left(1 - \frac{a}{\mathrm{A}}\right) + ·3936\right]$. Let us determine the unknown quantities.

The weight p, representing the sum of resistances to the motion of the wheel, is given by the conditions of the problem; the dynamic $p\,v$ being equal to the action of thirty horse-power, or to 16280·7 lbs. ft., and v being equal to 7·382 ft., we shall have $p = 2205·4$ lbs. To determine p', A and a, we must have the dimensions of the sheet of water which descends upon the curved bed, and consequently know P, which is precisely the quantity sought. Let us take at first an approximate value: for this purpose let us make $p' = 132·32$ lbs., and $\frac{a}{\mathrm{A}} = 0·1$; these quantities substituted in the equation, give $\mathrm{P} = 3043·5$ lbs., or $\mathrm{Q} = 48·736$ cub. ft. Since the velocity of the fluid sheet should be 7·382 ft., its section, or A, will be 6·6021 sq. ft. $\left(= \frac{48·736}{7·382}\right)$. We will admit 0·6562 ft. for the thickness of this sheet; its width, or that of the course, will be 10·061 ft. Leaving ·065 ft. of space between the sides of the course and the edges of the floats, we shall have $a = ·0656\,[10·061 + 2\,(·6562 - ·0656)] = ·7377$ sq. ft.: thus $\frac{a}{\mathrm{A}} = ·11173$. To get p', we will observe that eight floats at least plunge continually in the water of the course, and that they are submerged for a depth of ·5906 ft. in the direction of the radius, or ·6299 ft. in reality, by reason of their inclination of 160° to the radius. Since the width of the floats is 10·061 ft. − 0·131 ft., or 9·930 ft., and their thickness ·0984 ft., the weight of the fluid displaced by each of them will be 38·491 lbs. (= 9·9411 × ·6299 × ·09842 × 62·45): we will carry it up to 41·9026 lbs., on account of the ends of the supports, which also plunge into the water. This weight is as a force tending to lift the floats vertically: if we estimate it in the direction of the motion of rotation, it will be 41·9026 sin. i, i being the angle made by the radius of the wheel with the vertical, at the centre of immersion of the floats: this radius being 11·844 ft., and the dynamic radius being 11·745 ft., this force referred to the extremity of this last, or augmented in the ratio of these two numbers, will be 42·255 sin. i. For the eight floats, we must multiply 42·255 by the sum of the eight values of the sin. i, which will be 4·52049, the angles being, as a mean, 10°, 17½°, 25°, 32½°, 40°, 47½°, 55°, and 62½°. Thus we shall have $p = 191·01$ lbs.

Substituting these values in the equation, it will become $(2205·4 + 191·01)\ 7·382 = 0·90\,\mathrm{P}\ [6·562\ (1 - ·11173) + ·3936]$, and it will give for the second value of P 3158·8 lbs.; then $\mathrm{A} = 6·8523$ sq. ft., $a = ·7627$ sq. ft., $p' = 201·13$ lbs. For the third value of P, we have 3169·2 lbs., and 10·466 ft. for the width of the course. It will be well to augment this width when the water arrives in greater quantity; we may carry it to 10·63 ft., and the width of the floats will consequently be 10·508 ft. The force of the motor, 3169·2 lbs., falling 8·202 ft., is equivalent to forty-eight horse-power; the dynamic effect is but two-thirds of this. The rolling mill of which we have been speaking, and whose effect is but that of thirty horses, is of an ordinary kind: there are those which, with great velocity, produce the effect of fifty horses and upwards.

In the commencement of our observations upon wheels contained in a circular course, we remarked that it was best to increase the height of the course, so as to reduce as much as possible the distance between the float-board, which receives the first impulse of the fluid, and the reservoir. This is, in fact, the method of obtaining the greatest dynamic effect, with the least consumption of water; but this condition, though worthy of great consideration, is not the only one which determines the choice and disposition of the wheel to be used. For example, where we may have an abundance of water, we should consider less its economy, and rather regard the expense required in a construction made according to the rules which we have given: thus, instead of a small distance between the float-board impinged upon and the reservoir, we may sometimes have a very great one. This is the case with the iron-mills of the Pyrenees, where there are great falls and large streams; the wheels established there are otherwise remarkable for their simplicity and the solidity of their construction. We will give a brief description of them.

They are from 8·20 to 9·84 ft. diameter, including the floats; their circumference is formed by four segments or felloes of oak, extending from one arm to the other; these arms consist of two strong timbers, crossing the shaft, with a thickness of 0·49 ft. and a width of 1·148 ft. The floats, twenty-four in number, are 1·148 ft. deep and 0·2296 ft. thick: the middle is hollowed out to half the thickness. Upon this hollow, as upon the rimmed plates of Morosi, falls a great fluid vein, issuing from a nearly vertical trough, whose mean length is 9·84 ft. Above, there is a wooden reservoir, commonly with a depth of 6·56 ft., and as much in breadth. A little below the orifice of issue of the trough, the water strikes the floats; beyond this it, as well as the wheel, is contained in a circular curb or sweep, whose sides are 0·98 ft. distant from the edge of the floats.

Thus, upon a fall of 24·60 ft., or rather of 21·325 ft. real fall, admitting as a mean 3·2809 ft. of water in the reservoir, about 14·764 ft. will serve for the impulse, and there remains but 6·562 ft. for the weight to act. The orifice of the trough being usually 0·885 ft. by ·722 ft., the head being 13·124 ft., and taking 0·97 for the coefficient of contraction, the discharge or consumption of water will be 18·01 cub. ft.

Generally, in the forges of the Pyrenees, it is computed that, with a fall of from 22·96 to 26·25 ft., there is required 17·658 cub. ft. of water per second to move a hammer of from 1323 to 1543 lbs. a height of from 0·984 to 1·476 ft., which strikes from 100 to 120 blows per minute.

A bucket-wheel of 19·68 ft. diameter will produce a like effect with but 11·654 ft. of water only: the economy would be great, and advantage should be taken of it in a place where there is a scarcity of water; but where there is an abundance, it is possible that it may be better to establish one of the float-wheels just described, than to employ a wheel of double the height, nearly eight times the width, and whose construction, establishment, and maintenance will require a much greater expense.

Wheels moving in an Indefinite Fluid.—These wheels are principally used in boat-mills, or mills upon barges moored in the middle of rivers. We suppose, in this case, that there is no water-course or other construction to increase the natural velocity of the current on its arrival at the wheel. The diameter of these wheels never exceeds from 13 to 16·4 ft. The floats are usually twelve in number; it is thought, however, there may be an advantage in increasing this number to eighteen, and even to twenty-four. According to Fabre, who has given particular attention to this kind of machine, the height of the floats should not exceed $\frac{32}{100}$ of the radius of the wheel, measured to the centre of percussion; it will thus be at most a quarter of the entire radius; quite often it is but a fifth. This author made them to plunge entirely in the water, which may be an advantage in deep streams, when, by reason of some peculiar circumstance, the greatest velocity is below the surface of the current; but generally their force is greater when a portion of the float (in its vertical position) is elevated above the surface, the portion below remaining the same. Their width varies from 8 ft. to 16·4 ft.

Deparcieux, after having made the very important observation that water produced its greatest effect when acting by its weight (for it was before supposed that it exerted its greatest action by its impulse), having remarked that the water rose upon the floats, as upon an inclined plane, as soon as their edges reached the surface of the current, and that it acted then by its weight, supposed he could increase this action by giving the floats a greater inclination. To verify this conjecture, he made a small wheel, 2·85 ft. in diameter, carrying twelve floats 0·72 ft. in height by ·656 in width, and to which, by means of an ingenious mechanism, he gave such an inclination as he deemed best. This wheel raised different weights by means of a cord passed over a pulley fixed above it. It was placed upon the small river Bièvre, near Paris, in a place where the velocity of the current was 1·148 ft., and it there served for many series of experiments. We confine ourselves to citing the results of one of them. The arc plunged in the water was 96°, and the weight elevated was 2·85 lbs. The angle of inclination of the floats referred to the radius drawn to their interior edge, is noted in the first column of the subjoined tabulated form; and the time of one revolution of the wheel, corresponding to this angle, is in the second column. The angle of 30° was that of the greatest effect; it increased it in the ratio of 18 to 39.

Angle of Inclination.	Time of One Revolution.	Angle of Inclination.	Time of One Revolution.
°	"	°	"
0	39	30	18
10	25	40	20
15	19		

Bossut, with nearly the same apparatus, also made a series of experiments. In one of them, the inclination of the floats being successively 0°, 15°, 30°, and 37°, the effects obtained were found in succession to be as the numbers 1000, 1081, 1083, 1037. Here, also, the angle of 30° was found to be the most advantageous, though the increase was much less than in the experiment of Deparcieux.

Even if there should be some exaggeration in the results given by the last philosopher, it is none the less positive that the inclination of the floats increases the effect of these wheels. The best method of effecting this inclination appears to us to be that already mentioned, p. 1513 and p. 1516, which consists in inclining gradually the cross-pieces which form the floats.

Wheels with floats moving in an indefinite water-course having been the object of the first theory given upon wheels in motion, we shall now dwell for a while upon this matter.

Before the eighteenth century, machines had only been considered as in a state of equilibrium. Suppose it had been a hydraulic machine; after having estimated the effort of the current upon it, a subject to which Galileo and Descartes had made some contributions, they calculated the weight which, placed at the extremity of a lever, for example, should put it in equilibrium. If, then, it was necessary to move this weight, they either diminished it, or the length of the lever, until they attained the desired velocity. But to what point should the weight be diminished, or the velocity increased, that is to say, the velocity of the wheel, compared to the velocity of the current, to obtain the greatest effect? As to this, they were in complete ignorance.

Parent, of the Academy of Sciences in Paris, directed his attention to this object, and, after long researches, remarked that the increase of velocity should have a limit, beyond which the effect, in place of increasing, would go on decreasing; and consequently that there was a maximum, the knowledge of which would be of great importance in the establishment of machines. He sought

for it, and published the result of his calculations in a memoir, quite remarkable for the period in which it was written. After having unfolded some new principles upon the action of gravity, upon that of motors, and upon its measurement, he shows that in a hydraulic wheel established on a current, the effort of the water against the floats is only due to the excess of its velocity over theirs; and he makes it proportional to the square of this excess. He furthermore admits that it is equal to the weight of a prism which has for its base the part of the float struck by the fluid, and for its height the simple height due to the difference of these two velocities, so that we have $E = 62 \cdot 45\, s \frac{(V - v)^2}{2g} v$. In the case of *maximum* of effect, the variable factor $(V - v)^2 v$, being differentiated and made equal to zero, gives $v = \frac{1}{3} V$; that is to say, that for the greatest effect, *the velocity of the floats should be one-third that of the current.* This value of v, substituted in the expression of the effort, changes it to $62 \cdot 45\, s \frac{4}{9} \frac{V^2}{2g} = \frac{4}{9}\, 64 \cdot 45\, s\, h = \frac{4}{9}\, \Pi$, making $62 \cdot 45\, s\, h = \Pi$; thus the *effort will be* $\frac{4}{9}$ *of the weight of equilibrium* Π, employing the expression of Parent. Multiplying this effort by the velocity, $\frac{1}{3} V$, which answers to it, we have $62 \cdot 45 \frac{4}{27} s\, h\, V = \frac{4}{27} P\, h$; that is to say, that the *dynamic effect of such a wheel will be* $\frac{4}{27}$ *of the force of the current* ("*of the natural effect of the current*," in the words of the author).

Such is the theory of Parent, regarded as a great step made in the science of mechanics, and, in fact, it was the first. It was adopted by all the savans of Europe, and applied to all wheels with floats. Nevertheless, Borda, in Mémoires de l'Académie des Sciences de Paris, 1767, showed that it could not be applied to wheels with floats established in a course; that here all the particles which pass, with a velocity V, with a section s of fluid running in the course, arrive upon the wheels and impinge against them; that their number or volume is $s\, V$, and their mass $\left(\frac{62 \cdot 45\, s\, V}{g} = \right) 1 \cdot 9404\, s\, V$; that, in the impulse, they lose $V - v$ of velocity, and consequently $1 \cdot 9404\, s\, V\, (V - v)$ in quantity of motion; now, the quantity of motion lost by a fluid vein against a plate measures the force or effort of the impulse; thus the effort of the current against the floats will be $1 \cdot 9404\, s\, V\, (V - v)$. This theory of Borda, for wheels contained in a course, is universally admitted; it has been so in this article. It seems to us that it is applicable also to wheels moving in an indefinite fluid. Here, also, all the particles which pass with a velocity V, with a section s of current equal to that of the float, excepting some partial deviations, which we shall hereafter notice, arrive with an impulse; their volume is also $s\, V$; and they lose, in the collision, a quantity of motion expressed by $1 \cdot 9404\, s\, V\, (V - v)$.

For wheels established upon an indefinite water-course, as well as for those contained in a course, we have $E = n\, 1 \cdot 9404 . s\, V\, (V - v)\, v$. The section s will be that of the vertical portion of the float which plunges in the water, and n will be a coefficient comprising the corrections due to the deviations of the fluid fillets on their approaching the wheel, to the non-pressure at the back of the floats, &c.

The experiments of Bossut, made upon a small wheel, afford us this coefficient. It was 3·198 ft. in diameter; it had twenty-four floats, 0·442 ft. in breadth, and plunging 0·354 ft. in a current having a velocity of 6·081 ft. By means of a cord, wound round its axle, it was made to raise weights, gradually increased, which naturally reduced more and more the velocities. These weights and their respective velocities are noted in the adjoining Table. It may be remarked that the passive resistances of the machine are not comprised in the weight p'; so that $p' v$ represents only the useful effect, and not the total effect or force impressed upon the wheel. Consequently, the values of n, calculated by the formula $p' v = n\, 1 \cdot 9404\, s\, V\, (V - v)\, v$, will indicate too small coefficients or ratios between the real and theoretic effect; and the coefficient, which was 0·84 for good velocities, would probably have been about 0·90, if regard had been paid, as it should have been, to the passive resistances. On the other hand, M. Poncelet, who made observations upon the wheels of some boat-mills established upon the Rhine, at Lyons, and who has remarked that the theory of Borda expressed the results of experiments better than that of Parent, has only had 0·80 for the coefficient. Taking the mean term 0·85, we have $E = 1 \cdot 6493\, s\, V\, (V - v)\, v$.

p'	v	n		p'	v	n	
		Borda.	Parent.			Borda.	Parent.
lbs.	ft.			lbs.	ft.		
3·149	3·687	0·706	1·79	5·398	2·641	0·842	1·50
4·044	3·271	0·773	1·67	5·487	2·595	0·845	1·47
4·951	2·851	0·825	1·55	5·668	2·486	0·846	1·43
5·129	2·772	0·832	1·53	5·848	2·345	0·847	1·37
5·308	2·680	0·838	1·51				

We give, in the above Table, the coefficients derived from the formula of Parent. They present more variations, especially in the neighbourhood of the *maximum*, than those of the formula of Borda; which disposes us to favour the latter. Furthermore, his coefficients are less than 1; the others, on the contrary, are greater. Now, in machines there are so many causes of loss in the effect, causes which theory cannot take into account, that usually the results of calculation exceed those of experiment, and consequently the coefficient of reduction must be a fraction.

In the experiments above cited, the *maximum* of effect corresponds to the velocity of 2·641 ft., which is to that of V, or to 6·081, as 0·434 is to 1; making, then, $v = 0 \cdot 434\, V$, the above expression of effect becomes $0 \cdot 405\, s\, V^3$ (in ft. and lbs.); let us set it at $\cdot 400\, s\, V^3$, a very simple value of

the total effect which this wheel can produce. This is equivalent to $\cdot 4122\,P\,h$ (considering that $P = 62\cdot 45\,s\,V$, and $h = \cdot 01553\,V^2$). We have said (p. 1515) that the effect of wheels with floats, placed in a rectilinear course, was but $0\cdot 32\,P\,h$; that of wheels moving in an indefinite water-course would be about a third greater. But how much more considerable is the volume of water that has been used!

The paddle-wheels which steamboats carry on each of their sides, and which, like oars, produce a progressive movement, are also similar to these wheels. Consequently, the theory which we have given can be applied to them. The determination of their effect, however, becomes involved with a new velocity, that of the boat. Moreover, it requires the determination of two coefficients by experiment; one, relative to the resistance of the boat; the second regards the action of the fluid upon the wheels. They are placed in circumstances so different from those of boat-mills, that the coefficients determined for the latter cannot serve for the former without verification and some modifications. M. Poncelet, it is true, has made some experiments, by means of the dynamometer, upon the effort exerted by the wheels of a boat made fast in stagnant water: but these are not wheels of a boat in motion, and the experiments do not seem to us to be varied enough.

Until we have some experiments entirely satisfactory, profiting by those for which we are already indebted to the philosopher just named, and applying here the theory of Parent, which leads to a more simple expression, we will give, but provisionally, for the expression of the dynamic effect of a steamboat, and consequently for the expression of the force required to be impressed on it,

$$\cdot 1142\,S\left(\sqrt{\frac{S}{s}} + 3\right)(\pm V \mp u)^2;$$

S being the immersed section of midships of the boat, s the surface of that portion of the paddles which is immersed (that of two paddles supposed to be in a vertical position), V the velocity of the fluid, u the absolute velocity of the boat. The upper signs refer to the case where the boat ascends, and the lower signs to that where it descends the stream. The expression just given shows that the moving force to be employed will be so much smaller, as the impelled surface of the paddles is greater. But the trouble from large wheels upon boats causes us to give these paddles a width but two or three times their height, which is from a third to a fourth of the radius.

Wheels with Curved Floats.—Although undershot wheels with plane floats are not impressed with over a fourth or a fifth of the motive force applied to them, they have still some advantages, which lead to their frequent use; their establishment, even when well made, is attended with small expense, and they may receive quite a great velocity without any notable loss of their effect. M. Poncelet has undertaken, with a full preservation of these advantages, to avoid their enormous loss of force, and has accomplished his purpose in a most satisfactory manner by substituting curved floats for the plane. He gave a description of his important machine in a Memoir (for which a prize was awarded by the Institute in 1825), to which he afterwards made some additions, and which is in the hands of all engaged upon hydraulic machines; we shall confine ourselves to a succinct exposition of the theoretic principle of this wheel, and of the effect of which it is capable.

Let us suppose a wheel with curved floats, and so disposed that when a float has arrived at the bottom of the wheel, the inferior element of its curvature is horizontal and its superior elements vertical. We will at first admit that it is in a state of rest, and that a fluid fillet, animated with a velocity V, arrives horizontally upon its inferior element. Continuing to advance, it will rise up along the curve; during its elevation, gravity will by insensible degrees deprive it of its velocity V; and it will be entirely lost, conformably to the general laws of the ascent of heavy bodies, when it shall have attained the height $\cdot 015536\,V^2$: then it will descend; it will rejoin the float if it had passed it; it will follow it, pressing again upon it; gravity, during its descent, will restore the velocity of which it had deprived it during the ascent, and it will quit the float with the velocity V which it possessed on its arrival. Suppose, now, that the wheel turns with the velocity v at its periphery. As soon as the fillet, having always the velocity V, attains the inferior element of the lowest float, it will have, relatively to it, the velocity $V - v$; it is with this relative velocity that it commences advancing and ascending upon the curve; it will rise nearly to the height $\cdot 0155$ ft. $(V - v)^2$; and after descending, and on quitting the inferior element, it will have then in relation to it the velocity $V - v$. But this element moves itself with a velocity v in a direction exactly opposite; consequently, the absolute velocity of the fluid at its issue will be $V - v - v = V - 2\,v$. If $v = \frac{1}{2}\,V$, it will be $V - V$, or zero; that is to say, if the velocity of the wheel is half of that which the fluid had on its arrival, its absolute velocity on quitting the floats will be nothing. We have here, then, a motive current which experiences neither shock nor loss of velocity the instant it joins the wheel, and which possesses none at the moment of quitting it; it has then expended upon it all its motion and has communicated to it all its force; the two conditions for the production of the greatest possible effect, are thus fulfilled in the wheel of M. Poncelet, such as we have represented it. Thus, if P is always the weight of the fluid furnished by the current in 1″, and h_1 the height due to the velocity V, the effect will be expressed by $P\,h_1$.

But what is true for a simple fillet is no longer so for a mass or sheet of water of a certain thickness. Its molecules strike the floats, making an angle more or less great with the elements impressed, and so lose both velocity and force. This mass, at the moment of its quitting the floats, no longer moves in a direction exactly opposite to them. Moreover, as in all wheels which turn in a mill-course, a part of the motive water escapes, without exerting any useful action. So that the real effect will no longer be $P\,h_1$; it will be but a portion of it.

M. Poncelet has also determined the amount of this portion, that is to say, the ratio between the effect really produced, and the force employed to produce it; he has deduced it from many series of experiments.

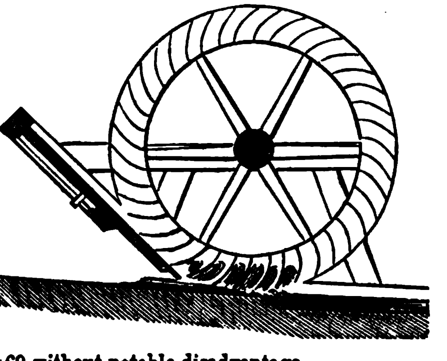
He first made use of a small model of a wheel, having a diameter of $1\cdot 64$ ft., and of the form

indicated in Fig. 2929; and he made thirteen series of observations analogous to those made by Smeaton upon a wheel with plane floats, p. 1515. We give in the following Table what relates to the determination of the *maximum* effect in eight of these series.

Height			Water Expended per Second.	Weight Raised and Resistances.	Velocity of Wheel.	Ratios.		
Of Opening of Gate.	Of Total Fall. H	Due to Velocity V. h^1	P	p	v	$\frac{v}{V}$	$\frac{pv}{Ph_1}$	$\frac{pv}{PH}$
feet.	feet.	feet.	lbs.	lbs.	feet.			
·0328	·456	·298	2·073	·183	2·165	0·50	0·65	0·42
	·797	·548	2·823	·376	3·477	0·59	0·63	0·44
·0656	·357	·256	3·572	·346	2·001	0·49	0·75	0·54
	·521	·397	4·366	·503	2·296	0·46	0·67	0·51
	·797	·633	5·844	·635	3·540	0·56?	0·61	0 49
·0984	·357	·239	5·315	·635	1·935	0·49	0·76	0·51
	·521	·381	6·550	·796	2·329	0·47	0·74	0·54
	·797	·617	8·580	1·168	3·248	0·52	0·72	0·56

M. Poncelet also operated, on a larger scale, upon a wheel 11·745 ft. in diameter, comprising, between two circular plates like those of bucket-wheels, thirty floats 1·246 ft. high in the direction of radius and 2·493 ft. wide. We give below the result of seven observations, remarking, 1st, that it was admitted, after some preliminary experiments, that the velocity V of the fluid on its arrival at the wheel was in the mean equal to the velocity due to the head h, and consequently that $h_1 = h$; 2nd, that p' represents solely the weight really raised by the friction brake, by means of which the experiments were made; thus $p'v$ is only the usual effect; while, in the preceding Table, p including the passive resistances pv was the dynamical effect.

2929.



It will be observed, in these two Tables, that the small openings of the gate rendered an effect much less than the others.

From these experiments and observations, M. Poncelet concludes,

1st. That the velocity of the wheel which gives the *maximum* of effect is 0·55 of the velocity of the current. It may, however, vary from 0·50 to 0·60 without notable disadvantage.

2nd. That the dynamic effect is not below 0·75 P h for small falls with great openings of the gate, nor below 0·65 for small openings and great falls.

3rd. That this same effect, compared to the entire force of the motor, or P H, will be 0·60 of it, and it may descend to 0·50 in very small openings.

Opening of the Gate.	H	h	P	p'		$\frac{v}{V}$	$\frac{p'v}{Ph}$	$\frac{p'v}{PH}$
feet.	feet.	feet.	lbs	lbs.	feet.			
·328	5·216	4·691	615 3	183	8·00	0·46	0·51	0·46
·688	4·002	2·657	974·8	264	6·79	0·52	0·70	0·56
·722	4·168	3·444	1160	302	8·92	0·60	0·68	0·56
·656	4·986	4·297	1182	352	8·63	0·52	0·60	0·52
·997	2·657	1·804	1157	227	7·41	0·69	0·81	0·55
	3·969	3·117	1438	383	8·63	0·61	0·74	0·55
	4·986	4·143	1784	476	9·61	0·59	0·63	0·52

For the cases usually presented in practice, and for wheels well arranged, with velocities which do not differ considerably from 0·55 of that of the current, we shall admit, having regard to the passive resistances E = 0·75 P h and E = 0·60 P H.

We have seen (p. 1515) that, for wheels with plane floats, the numerical coefficients of these two expressions of the dynamic effect were but 0·32 and 0·25; so that the effect of wheels with curved floats is more than double that of wheels with plane floats. This conclusion, to which we have arrived in such a manner as to combine the experiments which have been made on both, would lead us, in good constructions, to avoid entirely wheels with plane floats, and to use instead those with curved floats.

We refer here to the Memoirs of M. Poncelet, for the rules to be followed in the establishment of wheels with curved floats, and we make here only a few observations upon their characteristic part, the floats.

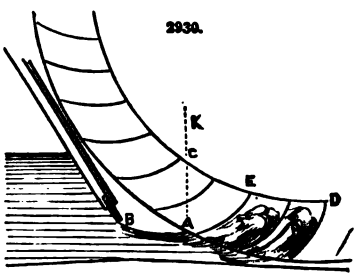
1st. Their number should be double that which we have indicated for wheels with plane floats (p 1513).

Their height in the direction of the radius, or the distance between the exterior and interior

circumference of the wheel, should always be more than a fourth of the effective fall; we should give it a third in falls of 4·593 ft.; and one-half in those which are below this.

3rd. The inferior element of the curve, which we have seen to make no angle, or nearly none, with the exterior circumference, when the sheet of motive water was extremely thin, will make one of 24°, 30°, and, generally, greater according as the sheet is thicker. We give this element its proper direction, and to the floats the curve which they should have, by means of the following draft; from the point A, Fig. 2930, where the surface of the current B A meets the exterior circumference, raise the perpendicular A K, and from the point C, where it intersects the interior circumference, with C A for radius, describe the arc A E; it will fix the form of the floats. They should be made of narrow planks, united like the staves of a cask, or of single large planks curved by fire, or of strong iron plates.

2930.



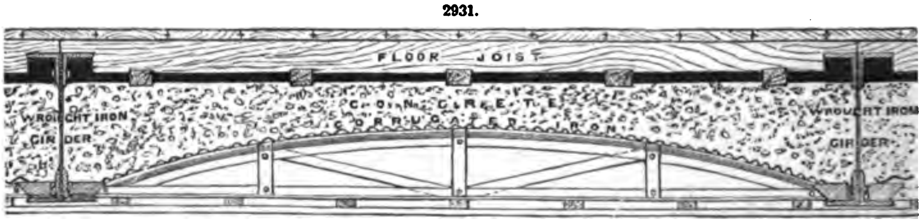
4th. A little beyond the vertical diameter of the wheel, we lower by a sudden step the floor of the tail-race, so that the water may experience no obstacle in issuing from the floats; otherwise, the effect would be subjected to a considerable diminution. Thus, M. Poncelet, who, in the last experiment of the preceding Table, had $p' v = 0·63 P h$, with a step of 0·984 ft., had but $0·54 P h$, the step being 0·262 ft.

In a place where the current presents a fall of 5·249 ft., we wish to establish a mill for sawing timber, which is to saw 129·168 sq. ft. per hour; that is, to make a cut 3·2809 ft. wide and 39·371 ft. in length. The wheel, or prime mover, is to have curved floats, and it is required to indicate its dimensions, as well as the quantity of water necessary to put and keep the mill in action. We know that a saw moved by a force equivalent to a horse-power, will saw, as a mean, 53·820 sq. ft. of timber in an hour; or, more generally, that the sawing of 10·764 sq. ft. is equal to a useful effect of from 325615 to 434154 lbs. ft., according to the quality of the timber to be sawed. Let us adopt, to prevent misconception, the last of these two numbers: the 129·168 sq. ft. to be sawn in an hour, or 3600″, will be equivalent to a useful effect of 1447·1 lbs. ft. a second. The resistances of the carriage, and of other parts of the machinery, will absorb nearly an equal quantity of action: so that the dynamic effect to be produced will be 2894·3 lbs. ft. (= E). Upon a fall of 5·249 ft., we will take 0·4921 ft. for dispositions relating to the mill-course, and 0·3937 ft. for half the opening of the gate; there will remain, then, for the head, but 4·3632 ft. ($= h$). With these numerical values of E and h, the formula $E = 0\ 75 P h$ gives $P = 884·7$ lbs. By the formula $E = 0·60 P H$, we have 1105·8 lbs. We will adopt this last value, and, making a small increase, we will count upon a consumption of 15·892 cub. ft. The head being 4·3632 ft., the velocity due to it will be 16·758. For, ·95 of this or for the velocity of the fluid in the course upon its arrival at the wheel, we shall have 15·92 ft.; the wheel will take nearly ·55 of this: thus the velocity at its periphery will be 8·756 ft. It corresponds to the mechanism adopted, to have the wheels make eight turns per minute. Consequently, we give it a diameter of 21·3258 ft.; the floats, in number sixty-eight, will be 1·968 ft. deep, in the direction of the radius, and their breadth between the shroudings 2·296 ft. It may be observed, in relation to this last dimension, that the thickness of the sheet of water in the course having to be nearly 0·5249 ft., it would be proper to give it a width above the wheel of 1·9027 ft. $\left(= \frac{15\ 892}{15·912 \times ·5249}\right)$. See Barker's Mill. Barrage. Boiler, p. 423. Canal. Damming. Hydraulics. Overshot Water-wheels. Poncelet's Water-wheel. Turbine Water-wheels. Undershot Water-wheels.

FLOORING. Fr., *Parquet, Carrelage, Tablier*; Ger., *Fussboden*; Ital., *Pavimento*; Span., *Piso.*

Floor (Moreland's), Fig. 2931.—Richard Moreland and Son's method of constructing flooring consists in fixing wrought-iron girders at given distances apart on the walls of buildings, and then placing between them on their lower flanges a number of wrought-iron bow and string lattice girders; and on the upper or curved surface of these laying corrugated iron throughout the floor. Concrete is then laid on the corrugated iron to the desired form and thickness, and sleepers, joists, and floor-boards may then be laid on the concrete in the ordinary manner. The ceiling joists are notched, or otherwise fixed on the lower part of the lattice girder, and are lathed and plastered in the usual way.

2931.



Long as well as short spans may be constructed on this system without the intervention of main girders, as the wrought-iron girders are made of great depth; they are kept close to both floor-boards and ceiling, thereby ensuring great rigidity and strength with little material. The angle-irons employed in constructing this floor being invariably used in one length throughout, and the rivets securing them to the web being closed by a powerful riveting machine, the girders are thus made very rigid, so that they deflect but little when loaded.

The air-space, which is included between the under-side of the corrugated iron and the ceiling, being a non-conductor of sound and also of heat, renders the floor sound-proof and safe under the action of fire, either from above or below the flooring. This air-space may be used for ventilating rooms by having suitable apertures provided in the ceiling to connect this space to special flues enclosed in the walls of the building. The air-space may also be used for warming purposes, provided the ceiling is specially constructed for this purpose.

The concrete laid on the corrugated iron forms a natural arch, and is prevented from exercising much lateral thrust by reason of the bow and string lattice girders with the corrugated iron acting as a permanent centring to the arch.

FLUE. Fr., *Carneaux, Tuyau de cheminée*; Ger., *Feuerzug, Rauchzug*; Ital., *Condotto dal fumo*; Span., *Conducto de humo.*

A *flue* is an air-passage; especially one for conveying smoke and flame from a fire. A flue is also a vertical division or compartment of a chimney. A steam-boiler flue is a passage surrounded by water, for the gaseous products of combustion, in distinction from *tubes* which hold water, and are surrounded by fire. Small *flues* are called *flue-tubes*. See Boiler. Chimney. Ventilation.

FLUME. Fr., *Biez, Canal d'écluse*; Ger., *Muhlengerinne*; Ital., *Gora*; Span., *Saetin.*

A stream; especially a passage or channel for the water that drives a mill-wheel; or an artificial channel of water for gold washing. See Overshot Water-wheels. Turbine Water-wheels.

FLY-WHEEL. Fr., *Volant*; Ger., *Schwungrad*; Ital., *Volanda*; Span., *Volante.*

See Algebraic Signs. Angular Motion. Engines, *Varieties of.*

FOLDING AND MEASURING MACHINE. Fr., *Machine à plier*; Ger., *Falzmaschine*; Ital., *Macchina da piegare e misurar panno*; Span., *Máquina de plegar y medir.*

See Measuring and Folding.

FORCE. Fr., *Force*; Ger., *Kraft*; Ital., *Forza*; Span., *Fuerza.*

See Acceleration. Anemometer. Angular Motion. Dynamometer. Dynamometer Car. Gunnery.

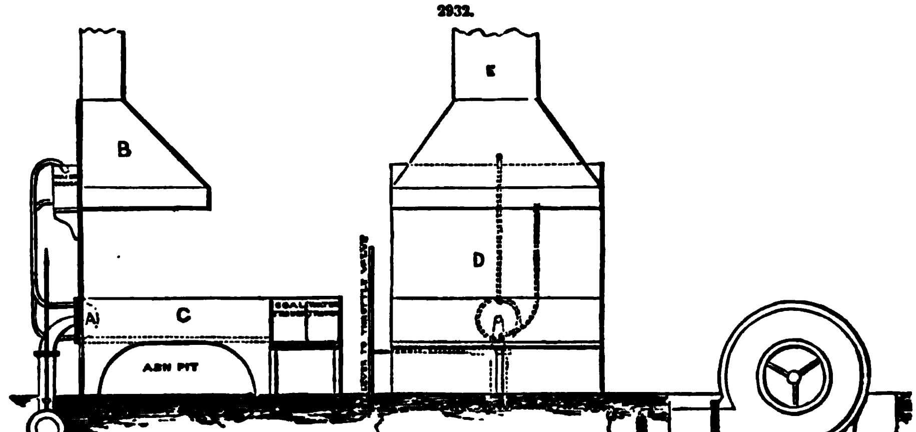
FORGE. Fr., *Forge*; Ger., *Esse*; Ital., *Fucina*; Span., *Fragua.*

A forge is an establishment where iron or other metals are wrought by heating and hammering: a *smithy*, a shop with its furnace, where iron and steel are heated and wrought; also, the place where iron is rendered malleable by *puddling* and *shingling*, is termed a forge.

Fig. 2932 gives the arrangement of a fan-forge employed at Gwynne and Co.'s Works, Essex Street, Strand.

This forge, Fig. 2932, is entirely constructed of iron.

2932.



C represents the hearth, in one casting, with the coal, shown on the right-hand side, so as to be within easy reach of the smith.

B is the bonnett, made of stout sheet iron, which connects immediately to the chimney E.

F represents one of Gwynne's improved fan-blowers, which is driven at about 1200 revolutions per minute, and sends the blast through the stand-pipe G, in which is the regulating valve; on the end of this pipe is the tuyere-iron A, which is fed by cold water from the small tank H, which is connected by the pipes, as shown, and which keeps up a continual circulation. The cold water enables the nose of the tuyere to last considerably longer than if not used.

For forging small round short rods, or keys, no tools are required except the ordinary fire-irons and the hand-hammer, tongs, and anvil-chisel, in the anvil, shown by Figs. 2933 to 2935.

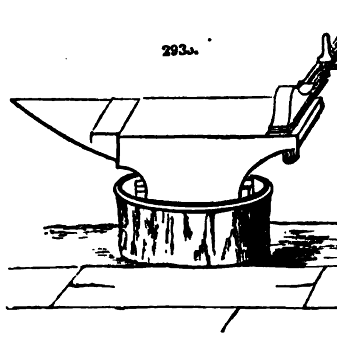
The pin should be forged to the proper diameter, and also the ragged piece cut off the small end, by means of the anvil-chisel, shown by Fig. 2935, while the work is still attached to the rod of steel from which it is made. After having cut and rounded the small end, it is proper to cut the key from the rod of steel, allowing a short piece to be drawn down to make the holder, by which to hold it in the lathe. This holder is drawn down by the fuller, and afterwards by the hammer. The fuller is first applied to the spot that marks the required length of key; the fuller is then driven in by the hammerman to the required diameter of the holder, the bottom fuller

being in the square hole of the anvil during the hammering process, and the work between the top and bottom fullers. During the hammering, the forger rotates the key, in order to make the gap of equal or uniform depth; the lump which remains is then drawn down by the hammers, or by the hand-hammer only, if a small pin is being made. If the pin is very small, it is more convenient to draw down the small lump by means of the set-hammer and the hammerman. The set-hammer is shown in Fig. 2939; and the top and bottom fullers by Fig. 2940

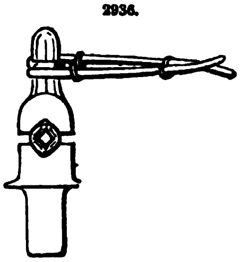
2933.

2934.

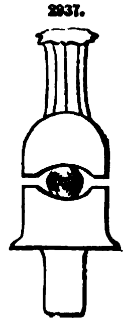
2935.



2936.

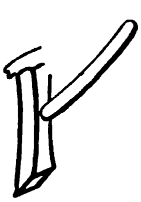


2937.

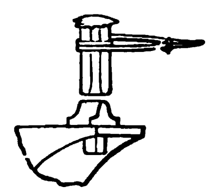


2938.

2939.



2940.



The double or alternate hammering by forger and hammerman should at first be gently done, to avoid danger to the arm through not holding the work level on the anvil. The hammerman should first begin, and strike at the rate of one blow a second; after a few blows the smith begins, and both hammer the work at times, and other times the anvil.

Figs. 2936, 2937, show the top and bottom rounding-tools, for rounding large keys. Large keys may be made without rounding-tools by rounding the work with a hand-hammer, and cutting off the pin by the anvil-chisel, instead of the rod-chisel, Fig. 2938. The rod-chisel is so named because the handle by which the chisel is held is an ash rod or stick, see Fig. 2936. A rod-chisel is thin for cutting hot iron, and thick for cutting cold iron. Fig. 2935 represents the anvil-chisel in the square hole of the anvil. By placing the steel while at a yellow heat upon the edge of the chisel, a small key can be easily cut off by a few blows of a hammer upon the top of the work.

To forge a key with a head involves more labour than making a straight one. There are three principal modes of proceeding, which include drawing down with the fuller and hammer; upsetting one end of the iron or steel; and doubling one end of a bar to form the head.

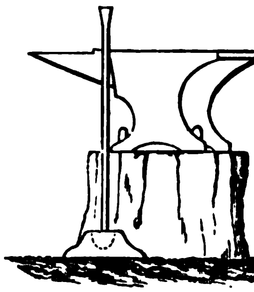
For proceeding by drawing down, a rod or bar of steel is required, whose diameter is equal to the thickness of the head required; consequently, large keys should not be made by drawing down unless steam-hammers can be used. Small keys should be drawn to size while attached to the bar from which they are made; the drawing is commenced by the fuller and set-hammer. Instead of placing the work upon the bottom fuller in the anvil, as shown for forging a key without a head, the steel is placed upon the face of the anvil, and the top fuller only is used, if the key required is large enough to need much hammering; but a very small key can be drawn down by dispensing with the top fuller and placing the bottom fuller in the hole, and placing the work upon the top, and then striking on one side only, instead of rotating the bar or rod by the hand. By holding the bar or rod in one position, the head is formed upon the under-side of the bar; and by turning the work upside down, and drawing down the lump, the stem is produced.

The upsetting of iron generally should be done at the welding heat, the upsetting of steel, at the yellow heat, except in some kinds of good steel, that will allow the welding heat. And both iron and steel require cooling at the extremity, to prevent the hammer spreading the end without upsetting the portion next to it. If the head of the key is to be large, several heats and coolings must take place, which renders the process only applicable to small work. A small bar can be easily upset by heating to a white heat or welding heat, and cooling a quarter of an inch of the end; then immediately put the bar to the ground with the hot portion upwards, the bar leaning against the anvil, and held by the tongs (Fig. 2941). The end is then upset, and the extremity cooled again after being heated for another upsetting, and so on until the required diameter is attained. When a number of bars are to be upset in this manner, it is necessary to provide an

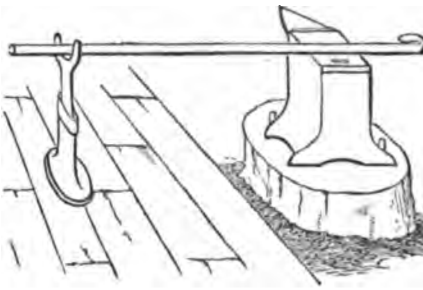
iron box, into which to place the ends of the bars, instead of upon the soft ground or wood flooring, injury to the floor being thereby prevented.

When the key-head is sufficiently upset, the fuller and set-hammer are necessary to make a proper shoulder; the stem is then drawn four-sided and rounded by the ◊ top and bottom tools. If the bar from which the key is being made is not large enough to allow being made four-sided, eight sides should be formed, which will tend to close the grain and make a good key.

2941.

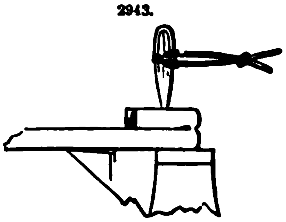


2942.



The third method of making keys with heads is the quickest of the three, particularly for making keys by the steam-hammer. By its powerful aid we are able to use a bar of iron an inch larger than the required stem, because it is necessary to have sufficient metal in order to allow hammering enough to make it close and hard, and also welding, if seamy. If the bar from which it is to be made is too large to be easily handled without the crane, the piece is cut from the bar at the first heat. But if the bar is small, it can be held up at any required height by the prop, shown in Fig. 2942. While thus supported, the piece to be doubled to make the head is cut three-quarters of the distance through the iron, at a proper distance from the extremity. The piece is then bent in the direction tending to break it off: the uncut portion being of sufficient thickness to prevent it breaking, will allow the two to be placed together and welded in that relation. A hole may also be punched through the two, while at a welding heat, as shown by Fig. 2943. The hole admits a pin or rivet of iron, which is driven into the opening, and the three welded together. This plan is resorted to for producing a strong head to the key without much welding; but for ordinary purposes it is much safer to weld the iron when doubled, without any rivet, if a sufficient number of heavy blows can be administered. At the time the head is welded, the shoulder should be tolerably squared by the set-hammer; and the part next to the shoulder is then fullered to about three-quarters of the distance to the diameter of stem required. In large work the fuller used for this purpose should be broad, as in Fig. 2944. After the head is welded, and the portion next to it drawn down by the fuller, the piece of work is cut from the bar or rod, and the head is fixed in a pair of tongs similar to Fig. 2945. Such tongs are useful for very small work, and are

2943.



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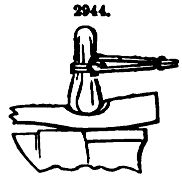

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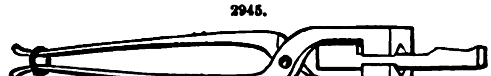


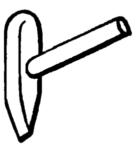
made of large size for heavy work. Tongs of this character are suited to both angular and circular work. They will grip either the head or the stem, as shown in the figure. While held by the tongs the thick lump of the stem that remains is welded, if necessary. Next draw the stem to its proper shape, and trim the head to whatever shape is required.

Bolts.—Bolts are made in such immense numbers, that a variety of machinery exists for producing small bolts by compression of the iron while hot into dies. But the machinery is not yet adapted to forge good bolts of large size, such as are daily required for general engine-making. Good bolts of large diameters can now be made by steam-hammers at a quick rate; and small bolts of good quality are made in an economical and expeditious manner by means of instruments named bolt-headers. There is a variety of these tools in use, and some are valuable to small manufacturers because of being easily made, and incurring but little expense. The use of a bolt-header consists in upsetting a portion of a straight piece of iron to form the bolt-head, instead of drawing down or reducing a larger piece to form the bolt-stem, which is a much longer process; consequently, the bolt-header is valuable in proportion to its capability of upsetting bolt-heads of various sizes for bolts of different diameters and lengths.

The simplest kind of heading-tool is held upon the anvil by the left hand of the smith, while the piece to be formed into a head is hammered into a recess in the tool, the shape of the intended

head. Three or four recesses may be drilled into the same tool, to admit three or four sizes of bolt-heads. Such a tool is represented by Fig. 2947, and is made either entirely of steel, or with a steel face, in which are bored the recesses of different shapes and sizes.

2946.



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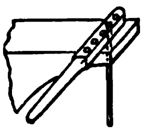
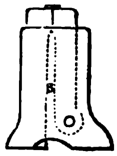


2948.



The pieces of iron to be formed into bolts are named bolt-pieces. When these pieces are of small diameter or thickness, they are cut to a proper length while cold by means of a concave anvil-chisel and stop, or by a large shearing machine. One end of each piece is then slightly tapered while cold by the hand-hammer, Fig. 2933, or a top-tool. This short bevel or taper portion allows the bolt to be driven in and out of the heading-tool several times without making sufficient ragged edge to stop the bolt in the hole while being driven out. Those ends that are not bevelled are then heated to about welding heat, and upset upon the anvil or upon a cast-iron block, on, or level with, the ground. This upsetting is continued until the smaller parts or stems will remain at a proper distance through the tool; after which, each head is shaped by being hammered into the recess. During the shaping process, the stem of the bolt protrudes through the square hole in the anvil, as indicated by Fig. 2947.

But when a large number of small bolts are required in a short time, a larger kind of heading-tool is made use of, which is named bolt-header. One of these, Fig. 2948, is a jointed bolt-header. The actual height of these headers depends upon the length of bolts to be made, because the pieces of which the bolts are formed are cut of a suitable length to make the bolts the proper length after the heads are upset; consequently, bolt-headers are made 2 or 3 ft. in height, that they may be generally useful.

The header represented by Fig. 2948 contains a movable block B, upon which rests one end of a bolt-piece to be upset; it is therefore necessary to raise or lower the block to suit various lengths of bolts.

All bolts, large and small, that are to be turned in a lathe require the two extremities to be at right angles to the length of the bolt, to avoid waste of time in centring previous to the turning process; and connecting-rod bolts and main-shaft bolts require softening, which makes them less liable to break in a sudden manner; and it is important to remember that hammering a bolt while cold will make it brittle and unsafe, although the bolt may contain more iron than would be sufficient if the bolt were soft. Great solidity in a bolt is only necessary in that portion of it which is to be formed into a screw. The bolt is less liable to break if all the other parts are fibrous, and the lengths of the fibres are parallel to the bolt's length. But in the screw, more solidity is necessary, to prevent breaking off while the bolt is being screwed, or while in use. However good the iron may be, the bolt is useless if the screw is unsound; and it is well to apply a pair of angular-gap tools, Fig. 2964, to the bolt-end while at welding heat.

Bolts of all kinds, large and small, are injured by the iron being overheated, which makes it rotten and hard, and renders it necessary to cut off the burnt portion, if the bolt is large enough; if not, a new one should be made in place of the burnt one.

Long bolts that require the lathe process are carefully straightened. This is conveniently effected by means of a strong lathe, which is placed in the smithy for the purpose. Long bolts are also straightened in the smithy by means of a long straight-edge, which is applied to the bolt-stem to indicate the hollow or concave side of the stem. This concave side is that which is placed next to the anvil-top, and the upper side of the bolt is then driven down by applying a curved top-tool and striking with a sledge-hammer. This mode is only available with bolts not exceeding 2 or 3 in. diameter and of length convenient for the anvil, because in some cases bolts require straightening or rectifying in two or more places along the stems. If a bolt 6 ft. in length is bent 1 ft. from one end, the bent portion is placed upon an anvil, while the longer portion is supported by a crane, and a top-tool is applied to the convex part. The raising of the bolt-end to any required height is effected by rotating a screw which raises a pulley, upon which is an endless chain; the work being supported by the chain, both chain and work are raised at one time. It is necessary to adjust the work to the proper height while being straightened; if not, the hammering will produce but little good effect. The amount of straightening necessary depends upon the diameters to which the bolts are forged, and also upon their near approach to parallelism. A small bolt not exceeding 1½ in. in diameter need not be forged more than a tenth of an inch larger than the finished diameter; a bolt about 2 in. diameter, only an eighth larger; and for bolts 4 or 5 in. in diameter and 4 or 5 ft. in length, a quarter of an inch for turning is sufficient, if the bolts are properly straightened and in tolerable shape. This straightening and shaping of an ordinary bolt is easily accomplished while hot, by the method just mentioned; other straightening processes, for work of more complicated character, will be given as we proceed.

After the bolts are made sufficiently straight by a top-tool, the softening is effected by a treatment similar to that adopted for softening steel, which consists in heating the bolts to redness and burying them in coke or cinders till cold. A little care is necessary while heating the bolts to prevent them being bent by the blast. To avoid this result, the blast is gently administered and the bolt frequently rotated and moved about in the fire.

Nuts.—The simplest method of making small nuts is by punching with a small punch that is held in the left hand; this punch is driven through a bar near one end of it, which is placed upon

a bolster on the anvil, while the other end of the bar is supported by a screw-prop. This mode is adapted to a small maker whose means may be very limited. By supporting the bar or nuts in this manner, it is possible for a smith to work without a hammerman. A bar of soft iron is provided, and the quantity of iron that is required for each nut is marked along the bar by means of a pencil, and a chisel is driven into the bar at the pencil-marks while the bar is cold. A punch is then driven through while the iron is at a white heat. Each nut is then cut from the bar by an anvil-chisel, and afterwards finished separately while on a nut-mandrel. The bar on the bolster is shown by Fig. 2952.

A more economical method is by punching with a rod-punch, which is driven through by a sledge-hammer. By this means several nuts are punched at one heating of the bar, and also cut from the bar at the same heat. A good durable nut is that in which the hole is made at right angles to the layers or plates of which the nut is composed. Some kinds of good nut iron are condemned because of these plates, which separate when a punch is driven between them instead of through them. By punching through the plates at right angles to the faces of the intended nuts, the iron is not opened or separated, and scarfing is avoided. Nuts that have a scarf-end in the hole require boring, that the hole may be rendered fit for screwing; but nuts that are properly punched may be finished upon a nut-mandrel to a suitable diameter for the screw required. Nuts for bolts not exceeding 2¼ or 3 in. diameter can be forged with the openings or holes of proper diameter for screwing by a tap. The precise diameter is necessary in such cases, and is attained by the smith finishing each nut upon a nut-mandrel of steel, which is carefully turned to its shape and diameter by a lathe. The mandrel is taper and curved at the end, to allow the nut to fall easily from the mandrel while being driven off. Such nut-mandrels become smaller by use, and it is well to keep a standard gauge of some kind by which to measure the nuts after being forged. The best kind of nut-mandrel is made of one piece of steel, instead of welding a collar of steel to a bar of iron, which is sometimes done.

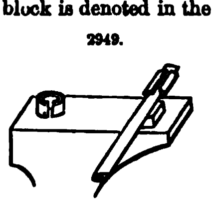
One punch and one nut-mandrel are sufficient for nuts of small dimensions, but large ones require drifting after being punched and previous to being placed upon a nut-mandrel. The drifting is continued until the hole is of the same diameter as the mandrel upon which the nut is to be finished. The nut is then placed on, and the hole is adjusted to the mandrel without driving the mandrel into the nut, which would involve a small amount of wear and tear that may be avoided. A good steel nut-mandrel, with careful usage, will continue serviceable, without repair, for several thousands of nuts.

The holes of all nuts require to be at right angles to the two sides named faces; one of these faces is brought into contact and bears upon the work while the nut is being fixed; consequently, it is necessary to devote considerable attention to the forging, that the turning and shaping processes may be as much as possible facilitated. If the two faces of the nut are tolerably near to a right angle with the hole, and the other sides of the nut parallel to the hole, the nut may be forged much nearer to the finished dimensions than if it were roughly made or malformed.

To rectify a nut whose faces are not perpendicular to the opening, the two prominent corners or angles are placed upon an anvil to receive the hammer, as indicated in Fig. 2953. By placing a nut while at a yellow heat in this position, the two corners are changed to two flats, and the faces become at the same time perpendicular to the opening; the nut is then reduced to the dimensions desired. If the nut is too long, and the sides of it are parallel to the opening, the better plan is to cut the prominences from the two faces by means of a trimming chisel, Fig. 2946, instead of rectifying the nut by hammering. Cutting off scrap-pieces while hot with a properly-shaped chisel of this kind, is a much quicker process than cutting off in a lathe.

Small connecting-bolts, not more than 2 or 3 in. in diameter, are made in an economical manner by drawing down the stems by a steam-hammer. Those who have not a steam-hammer will find it convenient to make a collar to be welded on a stem, in order to form a head, as shown by Fig. 2949. After being welded the head may be made circular or hexagonal, as required. The tool for shaping hexagonal heads is indicated by Fig. 2951. Such an apparatus may be adapted to a number of different sizes by fixing the sliding part of the tool at any required place along the top of the block, in order to shape heads of several different diameters. The movable or sliding block is denoted in the figure by S.

2949.



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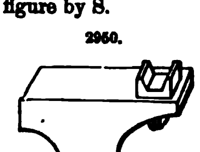

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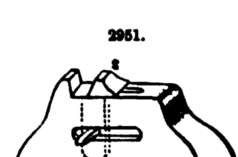

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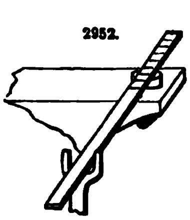

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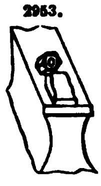

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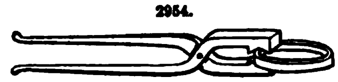

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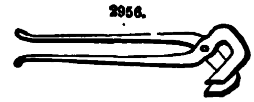
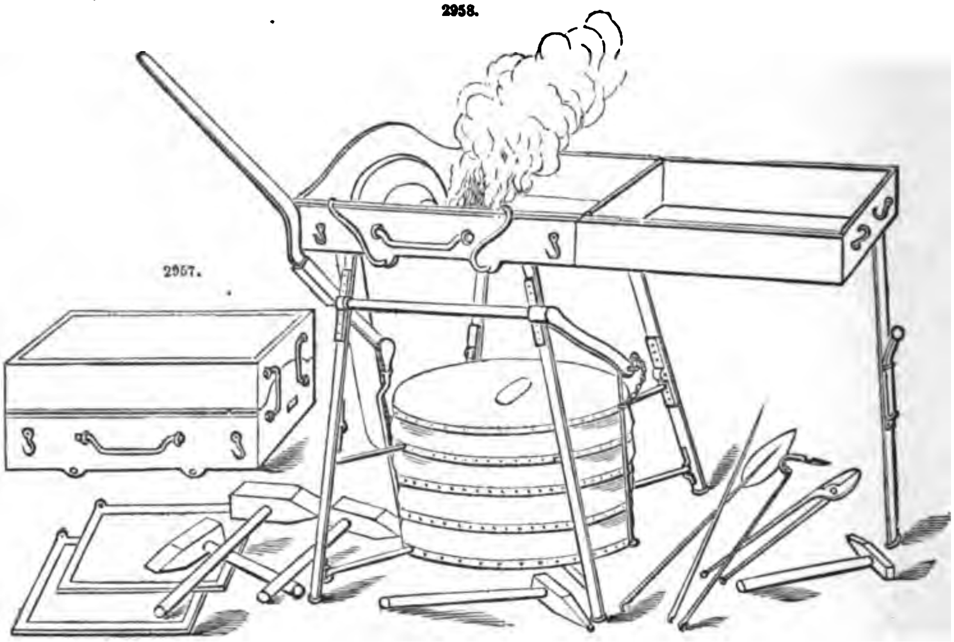


2955.

Tongs.—Fig. 2954 shows a curved-gap tongs, Fig. 2955 a bar-tongs, and Fig. 2956 a side-grip tongs.

The portable forge, Figs. 2957, 2958, contrived by Schaller, of Vienna, is well suited for military service. It consists of a box made of thin iron plates, 19 in. square and 9 in. high when closed, as shown in Fig. 2957. Within this box the bellows, legs, and all the tools, shown in Fig. 2958, are enclosed, and can be transported in a very convenient manner. The unpacking and setting up of

2958.



this forge when wanted can be effected in a few minutes, as all the parts are well made and fit together with firmness and accuracy, and there is no complexity in the arrangement. Schaller has delivered upwards of 200 of these forges to the Austrian army. This forge has been much employed in France and Belgium.

FORGING, MACHINERY FOR. FR., *Machines à forger;* GER., *Maschinen zum Schmieden;* ITAL., *Macchina da fucinare;* SPAN., *Maquinaria de forjar.*

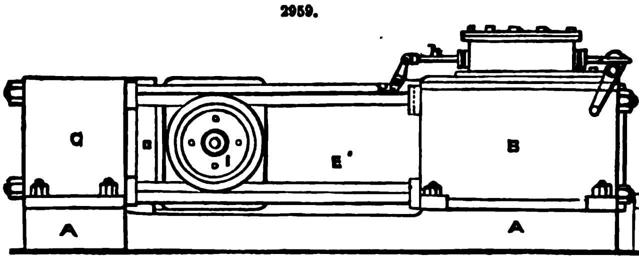
Machinery for Heavy Forging.—William Clay, of Liverpool, has designed machinery, Figs. 2959 to 2964, well adapted to that class of forging known as heavy forging, the object sought being to ensure sound forgings, which it is very difficult to obtain when manufacturing bulky articles, the thickness of the metal in which greatly and suddenly varies. In manufacturing, for example, marine-engine shafts with disc-couplings, the point of junction of the disc with the shaft will generally be found when cut to exhibit internal fissures, which greatly detract from the strength of the shaft. In order to avoid this defect, and to ensure solidity throughout the metal of large forgings, W. Clay proposes, when forming heads, collars, or flanges upon the ends of shafts or rods, to employ a horizontal hammer of peculiar construction, which is connected with and operated by a piston working in a horizontal steam-cylinder, and thereby materially to reduce the sectional thickness of the metal at the line of junction of the head, collar, or flange with the shaft.

In the accompanying engraving, Fig. 2959 shows in side elevation the kind of steam-hammer which Clay employs in manufacturing heavy forgings; Fig. 2960 is a partial longitudinal section of the same; Fig. 2961 is a transverse section taken at the line 1 2 of Fig. 2960, and looking in the direction of the arrow; and Fig. 2962 is a transverse section taken in the same line, but looking in an opposite direction. A A is the bed of the machine formed in one casting. To one end of this bed the steam-cylinder B is bolted, and to the other is secured a block C for receiving on its face the anvil D. The face of this anvil is shaped to correspond to the form the end of the shaft is intended to receive by its lateral expansion; and in order to allow of the anvil being changed to suit different sizes or kinds of work, it is made to fit into V's formed on the face of the block C. The anvil is U-shaped, as shown at Fig. 2962, and the block has a corresponding vertical hollow to enable it to receive the heated shaft that is intended to be brought under the action of the hammer. To facilitate the turning of the shaft on the anvil the block C is fitted with antifriction rollers *c c c* which support the shaft when it is presented to the hammer. E is the piston of the cylinder B, fitted to a cylindrical trunk E′, which carries at its other end the hammer-block.

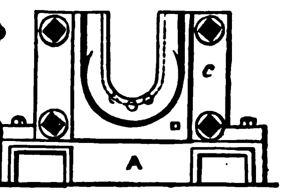
Fitted centrally in the face of this block is a conical piece G′, which forms the striking part of the hammer; its object is to form a cavity in the end of the shaft, and thus by reducing the thickness of the metal at that part to remove the liability of fissures occurring in the forging. H is the slide-valve, the rod h of which extends through the opposite ends of the valve-box. At its rear end this rod is formed into a link to receive a cam h_1, which is keyed to a cross-shaft h^2. This shaft rocks in bearings on the top of the cylinder B, and it is fitted with a handle, by raising or depressing which the attendant is enabled to operate the valve, and thus regulate the advance and retrograde movements of the hammer at pleasure.

To prevent the risk of damage to the machinery from inattention the valve-rod is jointed at its front end to the arm of a rock-shaft h^3 mounted in bracket bearings at the front of the cylinder B, and fitted with a pendent arm h^4 carrying an antifriction bowl. In a line with this bowl on the hammer-head is fitted an adjustable stop h^5, which as the piston is nearing its back-stroke will strike the bowl of the arm h^4 and rock the shaft h^3. This motion of the rock-shaft will, by reason of its connection with the valve-rod, cause the valve to advance and cut off the supply of steam to the cylinder, while at the same time it will stop the escape of the exhaust steam, and thus provide an elastic cushion for the piston to strike against.

2959.



2962.



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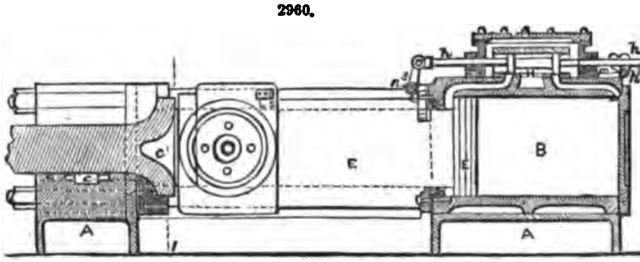

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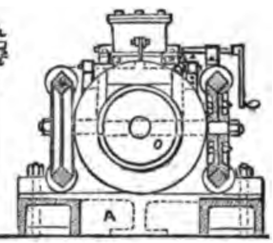
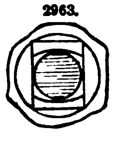
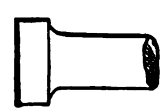


2963.



2964.



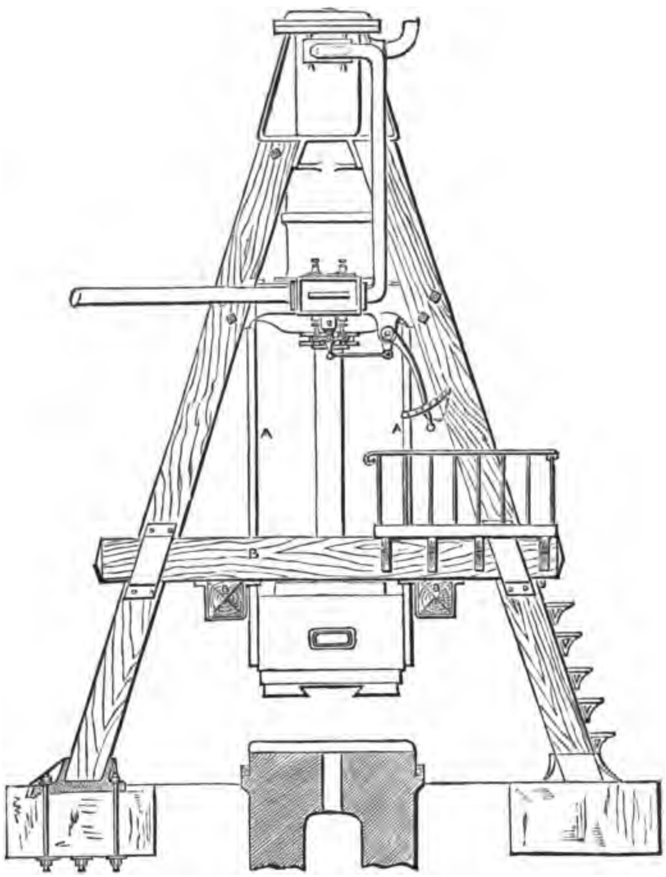
An incidental advantage derivable from making the cylindrical trunk E¹ of the large diameter indicated in the engraving is that it will allow of but a small amount of steam being used in the return stroke of the piston, while a powerful propelling force may be used for its advance. The hammer-head is fitted with a pair of V-grooved wheels I, which turn freely on a fixed axle that passes through the hammer-head. These wheels are intended to carry the weight and facilitate the traverse of the hammer, and for this purpose they run upon and between angular rails K K¹, which constitute also tie-rods for connecting the cylinder B and blocks C together, and enabling the machine the better to resist the strain to which it is subjected. The lower rails K serve as track-rails for the traverse to and fro of the hammer, and the upper rails K¹ assist in steadying the wheels on the track-rails.

In order to form a head or enlargement on a shaft by this machine, Clay first takes a shaft forged in any approved manner, and piles the end with pieces of wrought iron, after the manner indicated, Fig. 2963, so as to approximate roughly to the shape desired. The piled end of the shaft is next brought to a welding heat in a furnace and the pieces reduced to a solid mass in the usual way, whereby a shaft-head is obtained like that shown, Fig. 2964. Having thus prepared the shaft-forging, instead of finishing it in the ordinary way it is submitted to the action of the forging machine we have described, previously reheating the shaft, if that is required, to enable the machine to act efficiently upon it. The heated shaft is placed with its head opposite the hammer-head, as shown, Fig. 2960, in the block or rest C, furnished with antifriction rollers *c c* for facilitating the turning of the shaft when required. The head of the shaft overlies the anvil which forms the face of the block C, and the hammer by reason of its shape will, in delivering its blows, form a conical hollow in the head of the shaft, and thereby to a considerable extent reduce the bulk and equalize the thickness of the metal at the centre or the junction of the head with the shaft. By turning the shaft from time to time on its axis as the operation proceeds its head will be reduced under the blows of the hammer to a regular figure, requiring comparatively little turning to finish it. This mode of forging thick portions hollow also ensures a more equable contraction of the metal when cooling than hitherto, and the formation of fissures in large forgings of the character illustrated will be thereby avoided. To ensure the best practical effect the cooling of the metal, when the forging is completed, is commenced at the centre of the head by the application of a jet of water. By thus causing the metal to shrink towards the interior instead of the exterior the chief difficulty of obtaining sound forgings will be removed.

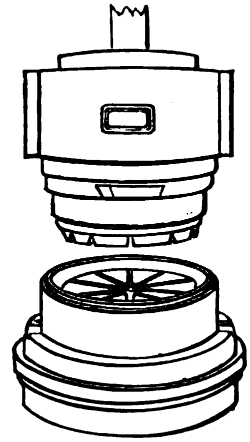
Figs. 2965 to 2971 are given to illustrate the method and machinery used for the manufacture of wrought-iron railway wheel centres by the stamping process of Arbel, at the Phœnix Iron-works, Rotherham.

Fig. 2965 is a front elevation of the steam-hammer, the weight of the moving parts of which is 12 tons. The standards are of Memel timber, and are four in number. The hammer-head is

2965.



2968.



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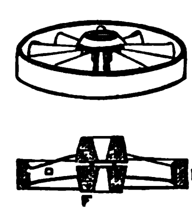

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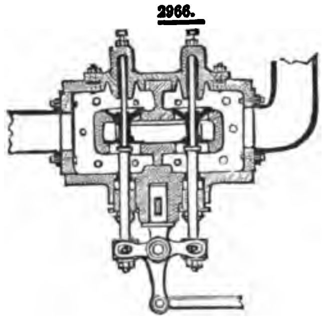

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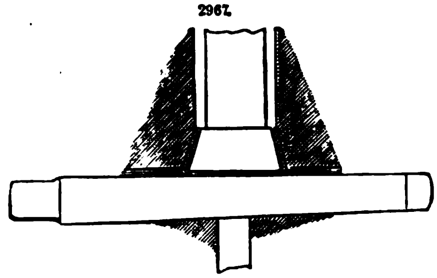
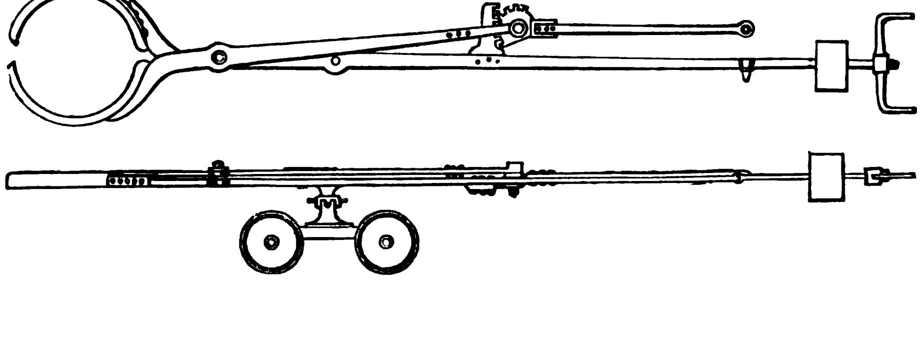


2971.



guided by four wrought-iron guide-bars, A A, the top ends of which are keyed into the cylinder base, and the lower ends bolted to the cross-timbers B B.

Fig. 2966 is a section of the valves.

The piston-rod is forged solid with the piston. Fig. 2967 shows the mode of connecting it with the hammer-head. The lower end of the rod is turned conically; and round it is placed the steel bush C, in two parts. The large wrought-iron key is drawn against the end of the rod, to tighten the rod into the hammer-head.

Fig. 2968 is a perspective view of the dies used, the top one being keyed into the hammer-head, and the bottom one keyed into the anvil.

Fig. 2969 is a perspective view of a wheel-centre when stamped, the rim, spokes, and nave being rounded so as to leave the dies.

Fig. 2970 shows the method of piling the material for a wheel-centre before being placed into the furnace. The spokes D are placed inside the rim E, with their inner ends enveloped between two nave washers F, the washers having indents stamped into them to receive the spokes.

Fig. 2971 shows the tongs used for lifting the material into an ordinary reverberatory furnace. When the material is raised to a welding heat it is again grasped by the tongs, and placed between the dies in the hammer, and welded with a few blows of the hammer into one solid piece. The tongs are supported on a carriage, which runs on rails from the furnace to the hammer.

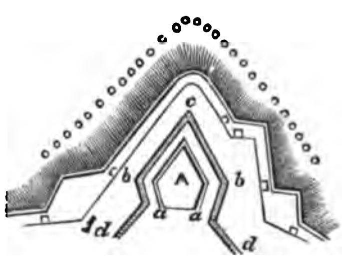
See Anvil. Bellows. Furnace. Hand-Tools. Iron. Puddling. Shingling. Steam-Hammer. Tin. Welding.

FORTIFICATION. Fr., *Fortification*; Ger., *Befestigungs oder Festungswerk*; Ital., *Fortificazione*; Span., *Fortificacion.*

Abattis, see p. 4.

Banquette.—A little raised way or foot-bank running along the inside of a parapet, on which the musketeers stand to fire upon the enemy in the ditch or in front of it.

2972.



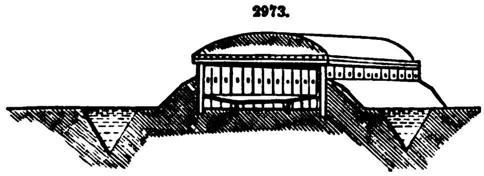
Barbette.—A mound of earth, on which guns are mounted to fire over the top of the parapet.

Bastion.—A part of the main enclosure which projects towards the exterior, consisting of the faces and flanks. Two adjacent bastions are connected by the *curtain*, which joins the flank of one with the adjacent flank of the other. The distance between the flanks of a bastion is called the gorge. In Fig. 2972, A is the bastion; *a*, curtain angle; *b*, shoulder angle; *c*, salient angle; *a*, *a*, gorge; *a*, *b*, flank; *a*, *d*, curtain; *b*, *c*, face.

Berme.—A narrow space, two, three, or more feet wide, left at the foot of the exterior slope of the parapet to retain earth that may slide down the bank.

Blockhouse.—An edifice or structure of heavy timber or logs for military defence, having its sides loop-holed for musketry. The sides and ends are sometimes much like a stockade, and the top covered with earth, as in Fig. 2973; there may also be a ditch round it.

2973.



Bonnet.—A part of a parapet considerably elevated to screen the other part and its *terre-plein*, usually from an enfilade fire.

Boyau.—A small trench, or branch of a trench, leading to a magazine or any particular point. They are generally called *boyaus of communication.*

Breastwork.—A low parapet for defence.

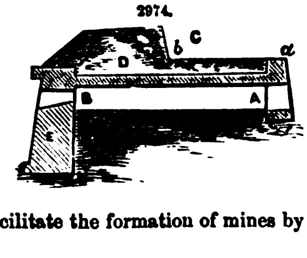
Bridge-head.—A fortification covering the extremity of a bridge nearest the enemy.

Brisure.—Any part of a rampart or parapet which deviates from the general direction.

Caponnière.—A work placed in a ditch for its defence by fire-arms, the defenders being covered on the sides and sometimes overhead. If on the side only, it is single; if overhead, it is double. The work often serves as a covered passage-way across the ditch.

Casemate.—A bomb-proof chamber, in which cannon may be placed to be fired through embrasures; or capable of being used as a magazine, or for quartering troops. A, D, Fig. 2974, is a section through a casemate; a gun at B would fire through the embrasure in the wall; a gun at C would fire *en barbette*, or over the parapet. D is the *parapet*; E the scarp wall, the outer face of which is the *scarp*. *a b*, *terre-plein.*

2974.



Chevaux-de-frise.—Pieces of timber traversed with wooden spikes, pointed with iron, 5 or 6 ft. long, used to defend a passage, stop a breach, or make a retrenchment to stop cavalry.

Counterfort.—A buttress, spur, or pillar, serving to support a wall or terrace.

Counter-mine.—A gallery underground, so constructed as to facilitate the formation of mines by which those of the enemy may be reached and destroyed.

Counterscarp.—The exterior slope of the ditch.

Covered way.—A secure road of communication all round a fort, outside the ditch, having a *banquette*, from which a grazing fire of musketry can be brought upon the *glacis.*

Crémaillère.—A horizontal outline, which is indented or zigzagged.

Crest.—The top line of a slope.

Deblai.—The volume of earth excavated to form the *remblai.*

Demi-bastion.—A half bastion, or that part of a bastion cut off by the capital, consisting of one face and one front.

Demi-lune.—A work constructed beyond the main ditch of a fortress, and in front of the curtain, between two bastions, intended to defend the curtain; a *ravelin.*

Embrasure.—An opening in a wall or parapet, through which cannon are pointed and discharged.

Enceinte.—The main enclosure; the wall or rampart which surrounds a place, sometimes composed of bastions and curtains; called also *body of the place.*

Envelope, or *Envelop.*—A mound of earth raised to cover some weak part of the works.

Epaulement.—A side-work, or work to cover sidewise, made of gabions, fascines, or bags filled with earth, or with earth heaped up. It is used to afford cover from the fire of an enemy, but is not arranged for defence by fire.

Esplanade.—The glacis of the counterscarp, or the sloping of the parapet of the covered way toward the country; a clear space between a citadel and the first houses of the town.

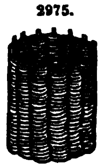
Flank.—That part of a bastion which reaches from the curtain to the face, and defends the opposite face; any part of a work defending another by a fire along the outside of its parapet.

Flèche.—A field-work, usually at the foot of a glacis, consisting of two faces, forming a salient angle pointing outwards from the position taken.

Front.—That portion of the enceinte between the capitals of the adjacent salient angle of the polygon fortified; or it includes this portion, or any other works within or beyond it which are between the two adjacent capitals and connected with it by defensive relations. *Bastioned front,* a curtain connecting two half bastions.

Gabion.—A gabion is a hollow cylinder, of wicker-work, Fig. 2975, or strips of sheet iron, resembling a basket, but having no bottom. It is filled with earth, and serves to shelter men from an enemy's fire.

2975.



Gallery.—Any communication which is covered overhead as well as at the sides.

Genouillère.—That part of a parapet between the merlons and beneath the sole of an embrasure.

Half-moon.—An outwork, composed of two faces, forming a salient angle, placed just in front of the curtain of the main work, and just beyond the main ditch.

Hornwork.—An outwork, composed of two demi-bastions, joined by a curtain. It is connected with the works in rear by long wings.

Lunette.—A detached bastion, Fig. 2976.

2976.

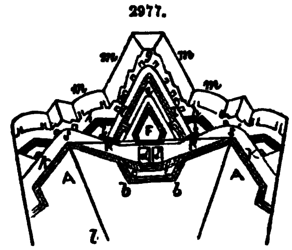
Magistral.—The line where the scarp of a permanent fortification, if prolonged, would intersect the top of the coping or cordon. It is the master line which regulates the form of the work; called also *Magistral line.*

Palisade.—A strong stake, one end of which is set firmly in the ground, and the other is sharpened; also, a fence made of palisades, used as a means of defence.

Parados.—A mound of earth thrown up to protect a battery or other outwork from a fire in the rear.

Parapet.—A wall or rampart to the breast, or breast high; especially a wall, rampart, or elevation of earth for covering soldiers from an enemy's attack from the front.

2977.

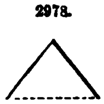


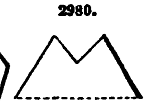
Postern.—A subterraneous passage between the parade and the main ditch, or between the ditches of the interior of the outworks.

Rampart.—An elevation or mound of earth round a place, upon which the parapet is raised.

Ravelin.—A detached work, with two embankments, which make a salient angle. It is raised before the curtain on the counterscarp of a place. In Fig. 2977, A A are bastions; *b b,* the curtain; *c c,* tenailles; *d d,* caponnière; *e,* ravelin; F, redoubt in the ravelin; *g g,* covered way; *h h,* re-entering places of arms; *i i,* redoubts in the same; *k k,* ditch; *l l,* ditch of ravelin; *m m m,* glacis; *s s,* exterior side; *s t,* capital.

2978. 2979. 2980.





Redan.—A work having two faces uniting, so as to form a salient angle towards the enemy. See Figs. 2978 to 2980.

Redoubt.—An outwork placed within another outwork, as at F and *i,* in Fig. 2977.

Remblai.—The earth or materials used in marking the embankments.

Revetment.—A facing of wood, stone, or any other material, to sustain an embankment when it receives a slope steeper than the natural slope.

Sally-port.—A postern gate, or passage underground from the inner to the outer works, to afford free egress for troops in a sortie.

Scarp.—The interior slope of the ditch nearest the parapet.

Tenaille.—An outwork in the main ditch in front of the curtain between two bastions; also an inverted redan.

Tenaillon.—A work constructed on each side of the ravelins, to increase the strength of the ravelins, procure additional ground beyond the ditch, or cover the shoulders of the bastions.

Traverse.—A work thrown up to intercept an enfilade, or reverse fire, along any line of work or passage exposed to such a fire.

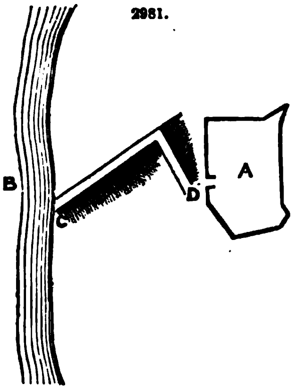
Zigzag.—This term is applied to the principle on which the attack of places is based; and this mode of approach had long been in use in a rude way, until perfected by Vauban.

Zigzag is not only the proper course by which to advance in sieges, but it is the method of con-

necting the parallels and places of arms, and finally arriving at the close of the attack or breaching batteries, and the work is usually effected by sap.

Sappers could run a zigzag up to the work in two or three hours, under the protection of musketry fire, and finally place a quantity of gunpowder for forcing the gate or barrier, or the destruction of a stockade or other slight defence, such as savages or insurgent inhabitants throw up on the spur of the moment.

2981.



The following example will show how a zigzag may be applied:—

Supposing it desirable to force a work A, Fig. 2981, an approach may be commenced from the hollow B, and a zigzag carried up to the entrance D, forming a short line of sap C D, where a quantity of powder could be fixed at the point D, which would on the explosion enable the attacking party to rush from the hollow, and, taking advantage of the confusion, carry the work.

FOUNDATION. Fr., *Fondation*; Ger., *Fundament*, *Grundwerk*; Ital., *Fondamenta*; Span., *Cimiento*.

See Construction. Bridge. Docks. Railway Engineering. Water-works.

FOUNDING AND CASTING. Fr., *Action de fondre*, *Fonte*; Ger., *Formen und Giessen*; Ital., *Fondere*.

Fire-proof material and durable crucibles are among the first things that require the founder's careful consideration.

Fire-proof Material.—The apparatus in which smelting or melting operations are performed is constructed of such materials as will not be seriously affected either by the heat applied or by the chemical action of the minerals or metals. Besides these conditions, economy is generally considered; but we find, in most instances, that the saving of first expense should be a secondary consideration where fire-proof material is in question. The materials used as fire-proof are sandstone, clay slate, shale, talcose slate, mica slate, granite, gneiss, porphyry, trap, and others, all of which are found native. Most of the fire-proof material used is clay or aluminous sand, kaolin, and clay slate, which are formed into bricks, slabs, or blocks, so as to suit particular purposes. The artificial fire-proof stone, or brick, does not generally resist the chemical action of the metallic oxides so well as native material; it is therefore necessary to use compact native rock, where the action of metallic oxides is to be resisted. Bricks, when well made and of good material, withstand the influence of heat very well; and in all cases where sudden changes of heat are expected, fire-brick must be used in preference to any other material.

Materials which are considered fire-proof must be of such a nature as to resist the effect of heat, that of the metallic oxides, and the reducing influence of carbon also. Peroxide of iron is proof against heat, against most metallic oxides, and also resists silex very well; but it does not resist carbon. When the latter substance is present, or even its compound gases, peroxide of iron is reduced to protoxide, and forms now a strong alkali for any silex or acid which may happen to come within its reach. Silex, clay, magnesia, lime, and baryta, are substances which are melted only by a very high heat, about 4000°, which is not required in any smelting operation. It is therefore sufficient if the fire-proof stones consist chiefly of one of these elements. Their combinations melt more readily than each by itself; but it is sufficient when the main body, the bulk of the stone, is formed of one of them.

Native Fire-proof Material.—Quite a number of rocks, slate, and shale, serve the purpose of refractory stones. Some of these are so perfect as not to require more labour than quarrying and dressing; others must be broken, and cemented again, in order to answer the purpose. As the refractory character of stones depends chiefly on the fusibility of their elements, we select them in most cases simply with reference to this quality; and as alumina, silex, magnesia, or lime, are fusible only at a degree of heat which is not often required in smelting operations, it appears to be all-sufficient, in order to secure durability, to select the most convenient form of these articles. This, however, is not the case. Pure lime is extremely refractory, but readily fusible if any silex is brought in contact with it; and as all fuel contains silex, the simple act of using coal or wood in a furnace built of the best kind of limestone will soon destroy it. In many instances, the presence of an excess of limestone is advantageous in smelting operations, and is frequently resorted to; in these cases, the inner walls of a furnace may consist of limestone, because the silicious matter of fuel and ore is absorbed by the flux, and little injury is done to the walls. Reflections of this kind generally decide the selection of rocks for fire-proof material, as we shall show hereafter. Native rocks are not often found to be of similar composition, not even in the same locality, for which reasons the selection of fire-proof stone is an operation which must be decided by actual test. It is very well known that the composition of sandstone, clay slate, mica slate, talc slate, gneiss, and granite, and also limestone, varies in different localities, and often in the same compass of a quarry.

Sandstone.—When sand, formed by the disintegration of rocky matter, is washed down in streams and deposited in the beds of large rivers, or the bottom of lakes and oceans, and when such deposits are elevated above water, or become dry land, the fine particles of lime, clay, oxide of iron, and other substances, which adhere to the particles of sand, and which more or less fill the crevices or spaces between the grains, become dry, and form in the meantime a chemical combination with the sand. The consequence of this close and intimate contact between these substances of opposite electrical qualities, is the formation of solid rock, in which the isolated grains of quartz are held together by a larger or smaller quantity of cement. The distinguishing quality of the sandstone for our purpose consists in the kind of cement and the quantity of it. If the cement is lime, we cannot expect the sandstone to be very refractory, for not only does silex melt readily with

lime, but the stone becomes brittle when exposed to fire. Peroxide of iron may form a good fire-proof stone with silex, provided the amount of iron is not too large, say not more than 5 per cent. The red, and often brown sandstone, of the Pennsylvania anthracite formation is a fire-proof stone of excellent qualities. This stone has been subjected to a slow heat in the earth, which cemented its particles firmly together. The best cement for sand, in the formation of sandstone, is silex itself, and the resulting rock is for these reasons denominated silicious sandstone, in contra-distinction to calcareous, ferruginous, or argillaceous sandstone. Silex is soluble in pure water, such as rain-water; and when such a solution is poured upon a bed of sand, it will penetrate and combine with or dissolve some of the sand; the consequence of which is, that the soluble parts are retained by the heavy grains, and these cannot be moved, the soluble silex forming a gelatinous cement for the grains of sand. Sandstone formed in this manner is, as a matter of course, very refractory, and liable to fracture when heat is suddenly applied. Slowly heated, and not exposed to changes of heat, this stone forms a durable hearthstone in blast-furnaces. Stones of this kind are frequently found in the bituminous coal region, and used as hearthstones. In many respects the argillaceous, in which clay forms the cement, is superior to the silicious sandstone; this refers particularly to those cases where a change of heat is inevitable. Clay does not form a strong cement, and such stones are generally found to be soft in the quarry, but harden on being exposed to the air or heat. These, however, do not generally resist high heat so well as silicious sandstones, and when fluxes come in contact with them when hot, they are soon melted. Sandstones which contain spangles of mica, or particles of pyrites, or which are coloured by any metallic oxides, particularly protoxides, are generally not fire-proof; still there are instances where such stones are used to advantage.

In the selection of sandstones for hearthstones we must be guided chiefly by experience. Coarse-grained stone, such as millstone grit, which occurs in the lower strata of the coal regions, is generally found to be of good quality. The coarse sandstone, in the higher strata of the coal formation, is not often adapted to resist a strong heat and the influence of fluxes, because its cement is chiefly lime, clay, and iron. In these upper strata, the fine-grained stone appears to be superior to the coarse grit. Transition sandstone, or old red sandstone, is generally found to be durable, particularly those kinds in which grains of white quartz of the size of peas, or small beans, are visible. Sandstone is peculiarly suitable to serve as a fire-proof stone; it resists heat to a higher degree than almost any other stone, and if compact, it is less attacked by fluxes than any other kind of rock; it has, besides, the advantage of being conveniently found, and it is easily quarried and cut into such forms as are required.

Sandstones may be tested by acids as to their composition, but the result cannot be depended upon, and is of no practical use. The only safe test is that by heat and fluxes. In order to investigate the refractory quality of a rock, a fragment of it is subjected to a gentle heat, which is not much higher than that of boiling water, for at least one week, or longer, after which it may be exposed to a higher heat. The latter is applied in a reverberatory furnace, or in a smith's forge, and should last at least for four or five consecutive hours, the heat being gradually raised to the highest pitch. The fragment, after being gently cooled and broken, must show a compact fracture, not vitrified in any part in the interior; its surface may be glazed, and it should not have lost much in weight. If, after heating it, the interior of the stone is brittle, porous, and friable, or if it is vitrified and strongly coloured, it will not resist the influence of fluxes, and it may be considered useless for resisting high temperatures. Quartz is extremely sensitive to changes of heat, and in all cases where it is subjected to them, it should not be used; the changes of heat caused by adding fresh fuel it cannot resist. Sandstone is therefore useless in air-furnaces, and in all furnaces which are subject to alternate charges of fuel, or draughts of cold air, such as puddling furnaces, the top of blast-furnaces, and all refining and reverberatory furnaces.

Clay and Clay-slate.—This mineral forms extensive rocks, and often whole mountain ridges: it is composed chiefly of silex and clay, but is never free from metallic oxides, and in most instances it contains carbon. The latter substances cause it to be fusible at a low heat, and its use as fire-proof stone is therefore very limited.

Slaty Clay is found in the regions of mineral coal; it forms a most valuable substance for the manufacture of fire-bricks, which are in fact chiefly composed of this clay; good fire-bricks are extensively manufactured of it; but it is of no use in its raw condition, for it requires a strong fire to make it sufficiently compact for adhering together. Some modifications of this kind of slate, when it contains a large amount of silex, and is stratified, assuming the form of shale, are used as fire-proof stone in furnaces, under steam-boilers, reverberatories, or at the top of blast-furnaces, also for in-walls; but there is little gained in its application; fire-bricks are cheaper in the course of time, because they last longer and require less repair.

Clay.—This substance is not often used in its raw state, but chiefly in the form of bricks, and as fire-proof mortar. Fire-clay is recognized by its colour, which is white, and is retained after exposure to a strong fire. Some clays will change their colour into a more or less grey, or red, on being calcined; these are not generally very refractory. Good clay, when fresh, emits a peculiarly disagreeable odour, an argillaceous smell; it also adheres strongly to the tongue, when the former is dry and the latter moist. The smell depends entirely on organic matter, for which clay has great affinity; it emits therefore that peculiar smell, although it is not actually necessary that organic matter should be present in the clay; breathing upon it may impart it. Clay may contain silex chiefly, and be a good fire-clay; it does not follow that clay which does not adhere to the tongue is not a fire-proof clay. The sources of good clay are feldspathic rocks; most of these clays are definite compounds of silex, alumina, potassa, lime, magnesia, oxide of iron, and water, but it is not necessary that a good clay should be a definite compound; on the contrary, the less such is the case the more refractory it is For these reasons most of the plastic clays are mixed with sand or pure quartz previous to forming bricks of them. Clay may be assayed and its composition determined previous to its application, but such an assay is of more interest to the scientific man than

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